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ORIGINAL ARTICLES

A LYSIMETER STUDY OF CROP ROTATIONS

I. CROP YIELDS AND SOIL PRODUCTIVITY

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(Received for publication on 6 September 1951)†

MANURING and proper soil-crop management are the two most important factors for maintaining and improving soil productivity. This can be best achieved by crop rotation, green manuring, growing of legumes, application of organic manures and mineral fertilisation.

If phosphorus is applied to the legumes, the legumes build up soil fertility and subsequent non-legume crops give very high yields. This is proved by the long-term experiments conducted in U.S.A., U.K. and other countries. Thorne [1924], Sears, *et al.* [1933] and Passore [1939] reported that not only yields of legumes were increased by phosphatic fertilisers but the subsequent non-legumes also gave increased yields. The field experiments conducted by Parr and Bose [1944] in India indicated that berseem (*Alexandrianum trifolium*) gave a very good response to phosphatic fertilisation (100-300 per cent) rise in yield over no manure and wheat following fertilized berseem also gave higher yields than that following unfertilized berseem [1945]. In their field experiments they had grown berseem (*Alexandrianum trifolium*) and cowpeas (*Vigna catiang*) for three years in *rabi* and *kharif* respectively and then grown wheat. In all the three years berseem received superphosphate at 132, 198 and 264 lb. P_2O_5 per acre.

In starting the present studies it was thought desirable to investigate how far the soil productivity could be increased by taking one crop each of berseem and cowpeas only. The doses of P_2O_5 tried were 100 and 200 lb. P_2O_5 per acre.

*In Parr and Bose's (*loc. cit.*) investigations information was not available in regard to (1) the influence of fertilisers on (*a*) crop composition (*b*) crop quality (*c*) mobilization of nutrients in the soil (*d*) the residual effects of fertilizers on the yield and composition of legumes and succeeding crops and (2) the extent to which soil productivity was affected by phosphatic fertilization of berseem as compared to fertilizing of cereal in a purely cereal rotation. It was, therefore, thought desirable to investigate this problem in detail and obtain information on the above aspects.

These studies have been conducted in 'filled-in' type of lysimeters which facilitated the study of the uptake of nutrients under different treatments and rotations. Two systems of rotation were used (*a*) a purely cereal rotation of wheat (*Triticum vulgare* Var. I.P. 165)—*maruwa* (*Eleusine coracana*)—wheat—*maruwa* and (*b*) a legume rotation of berseem (*Alexandrianum trifolium*)—cowpea (*Vigna catiang* Var. K. 390)—wheat (*Triticum vulgare* Var. I.P. 165)—cowpea.

* Studies of Parr and Sen [1948] with the permanent manurial series at Pusa, showed that green manuring with the legume sannhemp in conjunction with superphosphate has given strikingly high yields as compared to all other treatments. They attribute this to the beneficial effects of the association of organic matter and phosphate.

†Revised in April 1953.

Fertilisers were applied only to the first crop in each rotation. Crop yields were recorded and the crop, soil and leachate samples were analysed for various nutrients to throw light on the above aspects. These investigations were started in 1945-46 *rabi*. In these papers work of five seasons is reported and discussed.

The results are reported in two parts. Part I deals with crop yields and soil productivity, part II deals with crop composition, the removal of nutrients by crops and the quality of the crop.

MATERIAL AND METHODS

Soil. Soil for filling the lysimeters was obtained from Top Block 3A of the Indian Agricultural Research Institute farm area. The soil is a sandy loam.

Its chemical composition is given in Table I.

TABLE I

Chemical composition of soil (0-12″) used in filling the lysimeters (figures expressed on oven-dry basis)

Constituent	Percentage
Loss on ignition	1·08
Soluble silica	0·26
Insoluble sand and silica	86·46
Al_2O_3	5·3
Fe_2O_3	3·48
Total P_2O_5	0·057
Total K_2O	0·58
CaO	1·06
Total N	0·039
Nitrate N	0·0006
Available P_2O_5	0·0144
Available K_2O	0·0141
Organic carbon	0·22

Mechanical analysis of the soil

Sand	68·0 per cent
Silt	14·6 per cent
Clay	14·6 per cent
Total water soluble salts	100 parts per 100,000 parts
*p*H	7·2

Lysimeters. Lysimeters are of 'filled-in' type, $4\frac{1}{2}$ ft. long, $2\frac{1}{2}$ ft. wide and 6 ft. deep. Area of each lysimeter is 0·00026 or 1/4000 acre. The walls and bottom of the lysimeter are made of cement. In the bottom of the lysimeter are provided nine holes in each, arranged in a circle, to allow the drained water to percolate in the container, kept below each lysimeter. In the bottom, one foot layer of sand and pebbles was placed and then soil was filled up to $4\frac{1}{2}$ ft. All the precautions in filling and use of 'filled-in' type of lysimeter as discussed and reviewed by Kuhnke, *et al.* [1940] were taken.

Fertilizers were mixed with the top six inches of soil only.

Treatments and crop rotations

TABLE II

Rotation	Legume rotation		Cereal rotation				Legume rotation	
Lys. No.	1	2	3	4	5	6	7	9
Season								
1945-46 *rabi*	OB_1	P_1B_1	O.W.	N.W.	$P_1W.$	$NP_1W.$	..	..
1946 *kharif*	C	C	M	M	M	..	..	..
1946-47 *rabi*	W	W	W	W	W	W	$O.B_2$	P_1B_2
1947 *kharif*	C	C	M	M	M	M	C	C
1947-48 *rabi*	OB_2	P_2B_2	O.W.	N.W.	P_2W	NP_2W	W	W

O=untreated ; N=sulphate of ammonia at 80 lb. N/acre. P_1 and P_2=Superphosphate at 100 and 200 lb. P_2O_5/acre, respectively.
B_1 and B_2=Berseem at 30 and 60 lb. seed rate per acre respectively.
W=Wheat at 60 lb. seed rate per acre.
C=Cowpeas at 40 lb. seed rate per acre.
M=Maruwa at 30 lb. seed rate per acre.

The crops were irrigated with ordinary filtered water (tap water : *p*H 7·5, total soluble salts 10·6 pp. 100,000).

Agronomic observations on wheat

In each lysimeter ultimately 120 plants were maintained in four rows, 30 in each row. From the two central rows, 20 central plants in each row were selected for taking observations.

The height of plants, number of tillers per plant and number of earheads per treatment and weight of 1000 grains were recorded. The number of grains formed per treatment, the weight of earhead and the number of grains per earhead were calculated.

The date of earhead emergence and date of maturity were taken as the dates when the last earhead emerged and the last plant matured respectively.

The results obtained during the years 1945-46, 1947-48 are given in Tables III to VI.

TABLE III

Agronomic observations on wheat, 1945-46 and 1947-48

Rotation and year	*Cereal rotation-wheat-1st crop in rotation receiving fertilisers, 1945-46				*Cereal rotation-wheat-1st crop in rotation receiving fertilisers, 1947-48				†Legume rotation wheat-3rd crop in rotation, 1947-48	
Lysimeter No.	3	4	5	6	3	4	5	6	7	9
Treatment	O.W.	N.W.	P_1.W.	NP_1.W.	O.W.	N.W.	P_2.W.	NP_2.W.	OB_2.C.W.	P_1B_2.C.W.
1. Number of tillers per plant	3·4	3·0	4·6	6·2	2·9	2·6	3·1	3·5	3·4	4·0
2. Number of earheads per plant	..	..	..	..	1·7	2·3	1·5	3·0	3·4	4·0
3. Weight of earhead in gm. (calculated)	..	..	..	..	1·22	1·40	1·29	1·52	1·70	1·85
4. Weight of 1000 grains in gm.	38·65	35·39	41·85	43·65	35·70	39·74	38·08	44·76	45·10	45·84
5. Number of grains per earhead (calculated)	..	..	..	.	26	26	26	27	30	32
6. Date of ear emergence	14-2-46	14-2-46	9-2-46	3-2-46	21-1-48	21-1-48	18-1-48	6-1-48	19-1-48	9-1-48
7. Number of days after sowing on which ears emerged	79	79	74	68	75	76	73	61	74	64
8. Date of maturity	31-3-46	5-4-46	26-3-46	19-3-46	27-3-48	30-3-48	27-3-48	20-3-48	20-3-48	20-3-48
9. Number of days after sowing on which crop matured	124	129	119	112	142	145	142	135	135	135

*Cereal rotation = Wheat-maruwa-wheat-maruwa.
†Legume rotation = Berseem-cowpeas-wheat-cowpeas.
P_1 and P_2 = Superphosphate at 100 and 200 lb. P_2O_5 respectively.

TABLE IV

Yield of crops grown in cereal rotation

Crop	Wheat (1945-46)—1st crop				*Maruwa* (1946)—2nd crop				Wheat (1946-47)—3rd crop			
Lysimeter No.	3	4	5	6	3	4	5	6	3	4	5	6
Treatment	O.*W*.	N.*W*.	P_1.*W*.	NP_1.*W*.	O.W.*M*.	NW.*M*.	P_1W.*M*.	NP_1W. *M*.	OW.M. *W*.	NW.M. M.*W*.	P_1.W. M.*W*.	NP_1. M.*W*.
Yield of grain in gm./lys.	217·0	266·6	225·0	368·0	412	408	400	434	131	180	83	124·5
Per cent increase in yield of grain over control	..	22·8	3·7	69·5	..	—1	—2·9	5·4	..	37·4	—36·6	—5·0
Yield of straw in gm./lys.	307	381	318	607	2492	2517	2520	2692	237	446	151	256
Per cent increase in yield of straw over control	..	24·5	—29	97·9	..	1·0	1·1	8·0	..	91·6	—36·4	8·2

Crop	*Maruwa* (1947)—4th crop				Wheat (1947-48)—1st crop in 2nd rotation			
Lysimeter No.	3	4	5	6	3	4	5	6
Treatment	OW.M.W.M.	NW.M.W.*M*.	P_1.W.M.W. *M*.	NP_1W.M.W. *M*.	O.W.	N.W.	P_2.W.	NP_2W.
Yield of grain in gm./lys.	469	429	485	522	188	202	176	439
Per cent increase in yield of grain over control	..	—8·5	3·4	11·3	..	55·3	—6·4	133·6
Yield of straw in gm./lys.	1801	1865	1952	1975	313	418	286	638
Per cent increase in yield of straw over control	..	3·6	8·3	9·7	..	34·1	—8·6	108·6

TABLE V

Yield of crops grown in legume rotation

A. *Legume rotation followed in lysimeters 1 and 2*

Crop	Berseem (1945-46) 1st crop		Cowpeas (1946) 2nd crop		Wheat (1946-47) 3rd crop		Cowpeas (1947) 4th crop		Berseem (1947-48) 1st crop in 2nd rotation	
Lysimeter No.	1	2	1	2	1	2	1	2	1	2
Treatment	$O.B_1$	$P_1.B_1$	$O.B_1.C.$	$P_1B_1.C.$	$OB_1.C.W.$	$P_1B_1.C.W.$	$OP_1.C.W.C.$	$P_1B_1C.W.C.$	$O.B_2$	$P_2.B_2.$
Yield of fodder gm./lys.	973·6	3214·3	1383·5	2813·7	Grain 353 Straw 732	278 419	930	984	2426·2	4392·0
Per cent increase in yield over control	..	230	..	103	Grain — Straw —	—21 —43	..	6	..	81

B. *Legume rotation followed in lysimeters 7 and 9*

Crop	Berseem (1946-47) 1st crop		Cowpeas (1947) 2nd crop		Wheat (1947-48) 3rd crop	
Lysimeter No.	7	9	7	9	7	9
Treatment	$O.B_2$	P_1B_2	$OB_2C.$	$P_1.B_2.C.W.$	$OB_2.C.W.$	$P_2B_2.C.W.$
Yield of fodder gm./lys.	863	2167	1942	1185	Grain 557 Straw 703	713 825
Per cent increase in yield over control	..	151·1	..	—39	Grain — Straw —	28 17·2

TABLE VI

Yield of crops grown in legume rotation in lysimeters 1 and 2 (1947-48 to 1948-49)

Crop	Berseem (1947-48)—1st crop in second rotation		Cowpeas (1948)—2nd crop		Wheat (1948-49)—3rd crop	
Lysimeter	1	2	1	2	1	2
Treatment	$O.B_2$	P_2B_2	$O.B_2C$	P_2B_2C	$OB_2C.W$	$P_2B_2C.W$
Yield of fodder gm./lys.	2426·2	4392	992·2	1559·3	Grain 299·6 Straw 415·0	374·4 530·0
Per cent increase over control	..	81	..	57	Grain — Straw —	25 27·7

Discussion

Considering the direct effect of fertilisers on wheat crop (1945-46) and 1947-48 in cereal rotation, lysimeters 3, 4, 5 and 6, it might be observed that the application of phosphorus increased the rate of formation of tillers and the tillering capacity of plants. When nitrogen was also applied along with phosphorus, the maximum number of tillers was obtained (Table III). P-treatment of wheat resulted in early ear emergence and early maturity. When phosphorus was applied together with nitrogen the ears emerged much earlier and the rate of maturity was further accelerated than the application of nitrogen or phosphorus singly. Nitrogen treatment alone definitely delayed ear emergence and maturity (Table III). Phosphorus treated wheat had more number of tillers than nitrogen treated wheat but the number of effective tillers (i.e. tillers bearing earheads) was more in the latter than in the former. The total number of tillers and earheads were maximum in wheat receiving both nitrogen and phosphorus (Table III). This is due to the fact that in the soil nitrogen and phosphorus were deficient and either could not be efficiently utilised unless both were added. Nitrogen treatment of wheat increased the weight of earhead while combined application of nitrogen and phosphorus further increased the weight. Phosphorus application alone did not alter the weight of earhead (Table III).

Wheat receiving combined application of nitrogen and phosphorus gave maximum yield (70 per cent and 134 per cent more yield than control in 1945-46 and 1947-48 respectively) next in order being nitrogen treated (23 per cent and 55 per cent more yield than control in 1945-46 and 1947-48 respectively) and phosphorus treated (four per cent and six per cent over control in 1945-46 and 1947-48 respectively) wheats. The yields data thus indicated that in this soil nitrogen and phosphorus should be applied together to wheat, as phosphorus alone did not give favourable response. Nitrogen application alone (Table IV) gave only a limited response.

There were no residual effects on the yield of *maruwa* (1946) crop succeeding, wheat (Table IV).

Wheat (1946-47) in lysimeters 3, 4, 5 and 6 in cereal rotation in all lysimeters was definitely stunted and suffered from nutrient deficiency.

The yields were low indicating that the preceding two crops of wheat and *maruwa* had exhausted the available soil nutrients. This point was also borne out by the amounts of mineral nutrients taken up by the preceding two crops of wheat and *maruwa*, which are discussed in part II of this paper. N-treated lysimeter gave the maximum yield (37 per cent) followed by control and NP-treated lysimeter (—5 per cent). P-treated lysimeter gave least yield in this season as in the previous two seasons indicating that application of phosphorus alone in this soil did not give favourable crop response to wheat (Table IV).

The residual effects of previous manuring and cropping in cereal rotation were not markedly visible on *maruwa* crop (1947) as judged by crop yields.

From the above it would be seen that in cereal rotation maximum yields of all crops were obtained from the lysimeter receiving both nitrogen and phosphorus. Nitrogen application alone gave some response. Phosphorus treatment resulted in decreased yields of wheat and slightly more yields of *maruwa* as compared to control. No pronounced residual effects were observed.

In the legume rotation, considering berseem crops (1945-46) and (1947-48) in lysimeters 1 and 2 and the crop in 1946-47 in lysimeters 7 and 9, berseem receiving phosphate in the form of superphosphate gave very good response in the yield in all the three seasons (230 per cent, 81 per cent and 151 per cent respectively). The data obtained indicated that to berseem, phosphorus alone may be applied in this soil since berseem can meet its nitrogen requirements from the atmosphere (Table V).

As for the residual effect on cowpeas (1946) in lysimeters 1 and 2, cowpeas in P-treated lysimeter gave 103 per cent more yield than that of untreated lysimeter, indicating that previous phosphatic fertilization of berseem had a high residual effect for cowpeas (Table V).

Considering the residual effects on the preceding berseem and cowpeas on wheat, it was observed that wheat in legume rotation in lysimeters 1 and 2 was vigorous and healthy right from the beginning. P-treated berseem lysimeters gave lower yield of wheat (—21 per cent) than that given by untreated berseem lysimeter. (Table V), indicating that due to very heavy yields of the two preceding crops of berseem and cowpeas, soil in P-treated lysimeter was not so productive as in untreated berseem lysimeter. However, the yield of wheat in either of the lysimeters in the legume rotation was better than that of wheat in any one of the lysimeters where the residual effects of treatments in cereal rotation were in evidence.

One of the objects of these investigations was to study if soil productivity can be built up through phosphatic fertilization of berseem and if increased yields of wheat can be obtained as compared to wheat in untreated berseem rotation. In this series it was observed right from the beginning that the wheat in untreated berseem rotation was doing better than that in P-treated berseem rotation. Therefore in 1946-47 *rabi* another set of legume rotation with increased seed rate of berseem was started in lysimeters 7 and 9. The data obtained and conclusions arrived at are discussed later.

Yields of cowpea in untreated and P-treated lysimeter were practically the same (Table V).

All the four crops in P-treated berseem rotation (berseem-cowpeas, wheat-cowpea) combined together gave higher yields indicating that in this soil if legumes were included in the rotation phosphatic fertilization of legumes was very beneficial.

Legume rotation was started in 1946-47 in lysimeters 7 and 9 to investigate the conditions under which the P-treated berseem rotation would give more yield of wheat than that of untreated berseem rotation. In this series the seed rate of berseem was doubled while the P_2O_5 was applied at the same rate.

As for the residual effect of berseem (1946-47) on cowpeas (1947) in lysimeters 7 and 9, cowpeas in P-treated berseem rotation (lysimeter 9) gave 29 per cent less yield than that obtained from untreated berseem rotation (Table V). These results were contrary to the results obtained in lysimeters 1 and 2 in 1946.

Wheat in P-treated berseem rotation (lysimeter 9) was more vigorous, had more number of tillers and earheads, had more number of grain per earhead and heavier grain (Table III) and yielded more grain and straw than that of wheat in untreated berseem rotation (lysimeter 7, Table V).

In this series the phosphatic fertilisation of berseem had no residual effect on cowpea but had pronounced beneficial effect on wheat. It was felt that probably the yield of cowpeas and removal of nutrients by it in the rotation affected the yield of succeeding wheat crop. Earlier the interval between harvest of cowpea and sowing of wheat might not be enough to decompose larger amount of cowpea plant residues. In order to study the conditions under which increased yields of both the cowpeas and wheat crops in P-treated berseem rotation may be obtained, in the second rotation, which was started in 1947-48 *rabi* in lysimeters 1 and 2, after the completion of the first rotation, the seed rate of berseem and dose of phosphatic fertiliser were doubled. The results of this investigation for (1947-48) are given in Table VI. From this it can be seen that by following this seed rate and rate of application of P_2O_5, increased yields of berseem, cowpea and wheat were obtained, as compared to no manure treatment.

Comparing wheat (1946-47)—third crop in the legume rotation (lysimeters 1 and 2) with the wheat (1946-47)—third crop in cereal rotation (lysimeters 3, 4, 5 and 6) it was observed that wheat in legume rotation gave higher yield than that in any other treatment in the cereal rotation, thus indicating that the soil in the legume rotation after removing berseem and cowpeas was at a higher level of productivity than that in the cereal rotation after the removal of the two crops of wheat and *maruwa*.

Comparing wheat (1947-48)—third crop in legume rotation (lysimeters 7 and 9) with wheat (1947-48)—first crop in the cereal rotation (lysimeters 3, 4, 5 and 6) it might be noted that wheat in legume rotation was more vigorous, had more number of tillers, had more number of earheads, more number of grains per earhead and matured earlier than any other treatment receiving direct application of fertilisers in cereal rotation (Table III). These data thus indicate that in legume rotation more nitrogen and phosphorus were available to the crop from the soil than those available to the crop which received direct application of fertilisers. This point was borne out by the percentage composition of wheat grain with respect to nitrogen and P_2O_5 and removal of these nutrients by the wheat crops, which are discussed in Part II of this paper.

Wheat of untreated berseem legume rotation (lysimeter 7) and P-treated berseem legume rotation (lysimeter 9) gave more yield of grain and straw than any other treatment in the cereal rotation where wheat had received direct application of fertilisers (Tables IV and V). It is interesting to note that even untreated berseem rotation wheat yielded more grain and straw than that which received direct

application of 80 lb. of nitrogen and 200 lb. of P_2O_5 per acre thus indicating that mere introduction of legume in the rotation would meet the nitrogen and phosphorus requirements of the crop at least to that extent. Application of phosphorus to berseem in the rotation gave still higher yield indicating that nutrients were available to the crop in larger quantities than those available in untreated berseem rotation. The above type of response depends on the availability of other nutrient in the soil.

Summary

Two systems of four course, two year rotations, one including legumes and other having only cereal crops were laid out in lysimeters to study the influence of fertilisers on (*a*) the yield of crops receiving direct application of fertilisers (*b*) on the yield of subsequent crops in the rotation and (*c*) to what extent soil productivity is built up by phosphatic fertilisation of berseem in the legume rotation as compared to unmanured berseem rotation and a purely cereal rotation.

Cereal rotation

Influence of nitrogen and phosphorus singly and in combination on the formation of tillers, earheads, ear-emergence, maturity of crop, weight of earheads and yields has been discussed. It was noted that yield of wheat was determined by the number of effective tillers, *i.e.*, earheads and weight of earheads. It was further noted that in this soil, nitrogen and phosphorus should be applied together to wheat. No residual effects on succeeding crops were observed.

Legume rotation

Berseem gave a good response in yield as a result of phosphatic fertilisation. The residual effect on succeeding cowpeas was variable and it was noted that the yield of wheat succeeding cowpeas in the rotation was probably determined by the yield of cowpeas under the conditions of the experiment. There were no residual effects on cowpeas, fourth crop in the legume rotation.

When wheat in legume rotation (1947-48) was compared with wheat receiving direct application of fertilisers (1947-48) the former gave better yield than the latter, thus indicating that it is possible to meet the nitrogen and phosphorus requirements of the wheat crop to the extent of 80 lb. N and 200 lb. P_2O_5 per acre, by the introduction of legumes in the rotation and their phosphatic fertilization in this soil.

General conclusions

1. Cultivation of a legume like berseem in the rotation improves the soil productivity.

2. Phosphate manuring of berseem in heavy doses leads to enhancement of soil productivity to a marked degree. This treatment wipes out the deficiency of both nitrogen and phosphorus in the soil and in addition improves the quality of soil humus ; in short this treatment is superior to the direct application of nitrogen and phosphorus to the cereal crops in the rotation.

3. The improvement in the soil productivity so established has a cumulative effect as the rotation continues and the yields progressively increase till limited by some other soil deficiency.

4. The yield of wheat crop after growing berseem, cowpea in untreated lysimeter was equal to the yields of two wheat crops in unmanured lysimeter. The protein of the wheat grain in the former was greater than that in the latter (18 per cent and 11 per cent respectively). Moreover in the legume rotation excellent fodder for the animal was obtained in addition.

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A LYSIMETER STUDY OF CROP ROTATIONS

II. THE QUALITY AND CHEMICAL COMPOSITION OF CROPS

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(Received for publication on 6 September 1951)*

In Part I, the general lay-out of the experiments, the treatments and rotations practised have been described. The influence of fertilisers and different rotations on crop yields and soil fertility has been discussed therein. In this part the effect of fertilisers and rotations on the crop composition, and crop (wheat) quality are discussed.

The ultimate aim of maintaining and improving soil fertility is to ensure higher crop yields and nutritious food. It is well known that the fertility status of soil greatly influences the crop composition, which in turn plays a great role in the nutrition of man and animals. Soil fertility and crop composition and quality are therefore related factors. Hence greater stress has been laid to study the influence of different soil fertility factors particularly manures and fertilisers on crop composition.

Crop composition is influenced by climatic factors, soil characteristics and the nature of plant. The role of each of the above factors has been reviewed and discussed by Beeson [1941]. Climatic factors and most of the soil factors are beyond our control but the factor which we can modify and control is the nutrient status of soil. The experiments conducted to study the influence of soil and fertilisers on the crop composition have been reviewed by Shive and Robins [1939], Brown and Hallowell [1940], Vande Caveye [1940], Beeson [1941 and 1946] and Desai and Rao [1948].

The term quality of wheat has many possible meanings. The term must be considered in relation to the purpose for which the wheat of flour is to be used. [Thatcher, 1926 ; Bayfield, 1936]. Weight per bushel, diastase activity, percentage crude protein, strength of gluten and many other factors enter into the term quality. Bayfield [1936] has pointed out that for bread purposes the quality and quantity of protein are often measured. However, 'quantity' factor of protein is more important since superior varieties of wheat possess suitable protein qualities. Throckmorton [1926], Thatcher [1926] and Murphy [1930] considered weight per bushel and protein content as common measures of quality of wheat.

*Revised in April 1953.

In these investigations weight of 1000 grains and protein content of grain have been taken as quality indices.

Review of the literature indicates that nitrogen application generally reduces the weight of 1000 grains and gives a large number of shrivelled grains [Ames, *et al.* 1912 ; Thatcher, 1926 ; Murphy, 1930 ; Bose, 1942 ; Thothadri, 1942 ; Bioschot and Gouere, 1945] ; and phosphorus application gives plump and heavy wheat grains [Ames, *et al.* 1912 and 1917 ; McCool and Millers, 1924 ; Thatcher, 1926 ; Murphy 1930 ; Bose, 1942 ; Thothadri, 1942 ; Reitz and Myers, 1944].

Results

Table I on page 257 contains the percentage composition of the cereal rotation, while Table II on page 261 gives the corresponding data of wheat crop 1947-48 both in the cereal and legume rotations. The composition of crops grown in the legume rotation are given in Table III on page 262.

The quality factors of wheat, namely 1000 grain weight, percentage protein and grain colour of wheat in cereal and legume rotations are given in Table IV on page 264.

Discussion and conclusions

Cereal rotation

Considering the wheat crops (1945-46) and (1947-48), the first crops in the cereal-rotation (lysimeters 3, 4, 5, and 6 and Tables Ia and II), nitrogen and P_2O_5 accumulated in the grain while K_2O and CaO accumulated in the straw. N.P. treatment gave the best quality of wheat grain as judged from protein and P_2O_5 content, test weight and general appearance. This treatment resulted in the removal of maximum amounts of nitrogen, P_2O_5, K_2O and CaO by the crop. P_2O_5 at 200 lb. per acre increased the N, P_2O_5 and K_2O content in the grain. The results showed that in this soil both nitrogen and phosphorus were deficient, that nitrogen was a greater limiting factor and that for efficient utilisation of fertilisers and soil nutrient reserves both N and P should be applied together.

TABLE I

Percentage composition of and removal of nutrients by the crops grown in cereal rotation wheat (Triticum vulgare *Var. I. P. 165*)—maruwa Eleusine Coracanal-*wheat*-maruwa)

(a) *Wheat (1945-46) 1st crop in cereal rotation—lysimeters 3, 4, 5, and 6. Direct effect of fertilizers*

Lysimeter No.	*Treatment	Percentage composition of				Removal of nutrients lb./acre			
		N	P_2O_5	K_2O	CaO	N	P_2O_5	K_2O	CaO
Wheat grain									
3	O.W.	1·8	0·87	0·60	0·10	30·0	14·5	10·0	1·7
4	N.W.	*2·5*	0·68	0·60	0·11	52·2	14·1	12·4	2·2
5	P_1W	1·57	0·66	0·55	0·10	27·4	11·6	9·5	1·7
6	N.P_1W.	*2·71*	*0·92*	0·42	0·10	77·0	26·2	12·0	2·8
Wheat straw									
3	O.W.	0·27	0·072	2·3	0·41	6·6	1·7	55·4	9·8
4	N.W.	0·38	0·042	2·79	0·40	11·4	1·3	83·8	12·2
5	P_1W	0·20	0·11	1·56	0·39	5·0	2·7	39·0	9·8
6	NP_1W.	0·52	0·05	2·51	0·52	24·5	2·4	118·4	2 4·7
Grain and straw									
3	N.W.					36·6	16·3	65·4	11·5
4	N.+W.					*63·6*	*15·3*	*96·2*	*14·4*
5	P_1W.					32·4	14·3	48·5	11·5
6	NP_1W.					101·5	28·6	130·4	27·5
Percentage increase in removal of nutrients as compared to control									
3						..	..	..	..
4						37·7	6·2	47·0	24·7
5						12·1	12·5	25·8	..
6						177·4	78·4	99·4	38·9

*Explanation of symbols given on page 245.

(*b*) *Residual effects on* maruwa (*1946*-kharif) *2nd crop in cereal rotation* (*lysimeters 3, 4, 5 and 6*)

Percentage composition and removal of nutrients by maruwa (*1946*)

Lysimeter No.	Treatment	Percentage composition of					Removal of nutrients in lb./acre				
	Maruwa grain	N	Ash	P_2O_5	K_2O	CaO	N	Ash	P_2O_5	K_2O	CaO
3	OW.M.	1·54	2·69	0·62	0·76	0·93	48·2	83·9	19·3	23·9	29·0
4	NW.M.	1·45	2·79	0·62	0·79	0·82	44·9	86·4	19·3	24·4	10·0
5	P_1W.M.	1·33	3·25	0·73	0·86	0·69	41·2	93·2	22·1	26·0	20·9
6	NPW. M.	1·49	3·05	0·67	0·92	0.71	48·9	100·2	22·1	30·2	23·3
	Maruwa straw										
3	OW.M.	0·87	14·4	0·24	3·52	2·17	83·9	1,379·0	22·8	340·6	210·0
4	NW.M.	0·82	18·5	0·29	4·70	1·82	87·8	1,445·0	30·8	501·2	194·2
5	P_1W.M.	0·71	11·7	0·27	3·79	1·71	74·7	1,233·0	28·2	409·3	180·1
6	NP.W.M.	0·86	13·3	0·28	3·04	1·93	101·5	1,560·0	33·3	356·9	227·3
	Maruwa grain and straw	N	Ash	P_2O_5	K_2O	CaO	N	Ash	P_2O_5	K_2O	Ca O
3	(O.W.M.)	..	..	..	..	..	132·1	1,482·9	42·2	364·5	239·0
4	(N.W.M.)	..	..	..	..	..	132·7	1,531·7	50·1	525·6	204·3
5	(P_1W.M.)	..	..	..	..	..	115·9	1,331·2	50·2	426·3	200·9
6	(NP_1.W.M.)	..	..	..	..	..	150·3	1,660·2	55·4	389·2	*250·6

(c) Wheat (1946-47)—3rd crop in cereal rotation-residual effects (lysimeters 3, 4, 5 and 6)

Percentage composition of and removal of nutrients by wheat (1946-47)—*3rd crop in cereal rotation*

Lysimeter No.	Treatment	Percentage composition of					Removal of nutrients lb./acre				
		N	Ash	P_2O_5	K_2O	CaO	N	Ash	P_2O_5	K_2O	CaO
	Wheat grain (1946-47)										
3	(O.W.M.W.)	1·71	1·9	0·84	0·89	0·093	17·1	19·1	8·4	9·1	0·94
4	(NW.M.W.)	1·86	1·94	0·89	0·91	0·062	25·8	26·9	13·4	12·7	0·94
5	(P_1W.M.W.)	1·41	1·96	1·09	0·71	0·094	11·2	12·5	6·9	4·5	0·60
6	(NPW.M.W.)	1·72	0·09	1·02	0·97	0·062	16·5	20·0	7·8	9·3	0·60
	Wheat straw										
3	(OW.M.W.)	0·46	11·14	0·09	1·90	0·29	6·2	151·5	1·3	25·8	4·0
4	(NW.M.W.)	0·26	8·75	0·15	2·74	0·61	7·0	234·1	4·0	73·2	16·5
5	(P_1W.M.W.)	0·25	8·55	0·09	1·60	0·53	2·2	77·1	0·3	14·4	4·8
6	(NP_1W.M.W.)	0·40	10·24	0·23	1·97	0·53	5·1	141·3	3·1	27·2	7·2
	Wheat grain and straw combined										
3	(O.W.M.W.)	..	..	..	..	..	23·4	170·6	9·7	34·9	4·9
4	(NW.M.W.)	..	..	..	..	..	32·8	261·0	13·4	85·9	17·3
5	(P_1W.M.W.)	..	..	..	..	..	13·5	89·6	7·7	18·9	5·4
6	(NP_1W.M.W.)	..	..	..	..	..	22·1	161·3	12·9	36·5	7·8

(*d*) Maruwa (*1947*)—*4th crop in cereal rotation* (*lysimeters 3, 4, 5 and 6*)

Percentage composition of and removal of nutrients by maruwa *crop* (1947—kharif) —*4th crop in cereal rotation*

Lysimeter No.	Treatment	Percentage composition of					Removal of nutrients lb./acre				
		N	Ash	P_2O_5	K_2O	CaO	N	Ash	P_2O_5	K_2O	CaO
	Grain										
3	(OW.M.W.M.)	1·46	3·7	0·65	1·7	0·89	52·7	133·1	23·3	61·0	31·9
4	(NW.M.W.M.)	1·40	4·12	0·71	1·64	0·93	46·1	135·5	23·4	54·0	30·6
5	(P_1W.M.W.M.)	1·39	3·63	0·76	1·72	1·00	54·6	142·9	30·0	53·8	39·3
6	(NP_1W.MW.M.)	1·42	4·03	0·63	1·62	0·92	57·4	162·3	25·5	65·4	36·9
	Straw										
3	(OW.M.W.M.)	0·95	10·53	0·22	3·12	2·17	44·0	446·3	9·5	137·6	95·8
4	(NW.M.W.M.)	0·82	9·76	0·18	2·94	2·3	34·1	405·6	7·5	122·3	95·4
5	(P_1W.M.W.M.)	0·78	12·19	0·22	2·79	2·6	36·8	571·9	10·6	131·1	122·0
6	(NPW.M.W.M.)	0·84	10·2	0·23	2·64	2·6	40·3	491·9	11·2	127·5	125·9
	Grain and straw										
3	(OW. M.W.M.)	..	..	..	..	..	96·7	579·4	32·8	198·5	127·6
4	(NW.M.W.M.)	..	..	..	..	..	80·2	541·1	30·9	176·3	126·0
5	(P_1W.M.W.M.)	..	..	..	..	..	91·4	714·8	40·6	189·9	161·0
6	(NPW.M.W M.)	..	..	..	..	..	97·7	652·2	36·7	192·9	162·8

TABLE II

Wheat 1947-48 (lysimeter experiment)

Lysimeter No.	Percentage composition of					Removal of nutrients in lb./acre.				
	Ash	N	P_2O_5	K_2O	CaO	Ash	N	P_2O_5	K_2O	CaO
Wheat straw										
3 Control	22·07	0·33	0·092	1·48	0·65	548·3	8·1	2·2	56·8	16·2
4 N	13·83	0·33	0·052	2·74	0·74	469·0	11·1	1·8	92·8	25·1
[illegible] $P_2O_5(P_2)$*	14·41	0·22	0·16	1·93	0·46	329·9	5·1	3·6	34·8	10·5
[illegible] $NP_2(NP_2)$	9·5	0·28	0·128	1·82	0·69	489·2	14·5	6·6	93·6	34·3
7 Wheat after cowpea after untreated berseem	13·96	0·39	0·1	3·06	0·64	304·4	22·2	5·9	176·5	36·3
[illegible] Wheat after cowpea followed P-treatment berseem	14·82	0·49	0·13	2·8	1·13	980·7	32·9	8·8	187·6	75·7
Wheat grain										
[illegible]	1·89	1·42	0·82	0·72	0·14	28·2	21·3	12·2	10·8	2·1
4	1·63	2·1	0·7	0·59	0·15	37·6	28·8	16·2	13·5	3·4
5	2·04	1·81	1·07	0·9	0·10	28·4	25·2	14·9	12·5	1·4
6	1·96	1·99	1·02	1·03	0·11	68·2	69·3	35·3	35·9	4·0
7	1·61	2·72	0·81	0·66	0·097	70·7	119·8	35·7	29·1	4·4
9	1·82	2·37	0·73	0·91	0·14	73·8	132·9	40·8	41·3	7·8
Grain and straw										
3						576·6	29·4	14·5	47·6	18·8
4						506·6	59·9	17·9	106·3	28·5
5						356·3	30·3	18·5	47·3	11·9
6						557·4	83·8	41·9	129·5	38·2
7						875·1	142·0	41·6	205·6	41·1
9						1,063·5	166·6	49·6	238·7	83·6

*P_2 = Super at 200 lb. P_2O_5 per acre

TABLE III

Crops grown in legume rotation (berseem-cowpea, wheat-cowpea)

(a) Berseem (1945-46, 1946-47, 1947-48)—direct effect of fertilizers

	Berseem (1945-46)		Berseem (1947-48)		Berseem (1946-47)	
Lysimeter No.	1	2	1	2	7	9
Treatment	$O \cdot B_1$	$P_1 \cdot B_1$	$O \cdot B_2$	P_2B_2	$O \cdot B_2$	P_1B_2
Per cent composition—						
N	3·45	3·47	4·13	4·26	5·59	5·43
P_2O_5	0·43	0·63	0·46	0·83	0·83	0·89
K_2O	3·92	3·20	3·88	2·63	6·51	4·17
CaO	2·27	2·18	3·13	3·64	5·97	5·13
Removal of nutrients in lb./acre						
N	42·8	138·0	118·3	183·6	63·7	135·6
P_2O_5	5·4	25·0	13·3	35·8	7·6	24·3
K_2O	40·6	128·5	110·9	113·5	74·2	104·3
CaO	28·3	86·7	98·4	160·9	68·1	129·8

(b) Cowpeas (1946 and 1947)—residual effects

Crop	Cowpeas (1946)-2nd crop in legume rotation		Cowpeas (1947)-2nd crop in legume rotation		Cowpeas (1947)-4th crop in legume rotation	
Lysimeter No.	1	2	7	9	1	2
Treatment	$(OB_1 \cdot \underline{C})$	$(P_1B_1\underline{C})$	$(OB_2 \cdot \underline{C})$	$(P_1B_2\underline{C})$	$(OB_1.C.W.\underline{C})$	$(P_1B_1 \cdot C.W.\underline{C})$
Per cent composition—						
N	3·4	3·21	2·78	3·33	2·53	2·82
P_2O_5	0·47	0·62	0·39	0·41	0·36	0·38
K_2O	2·31	1·97	0·94	0·93	2·51	2·00
CaO	4·5	4·56	3·20	4·41	4·21	6·35
Removal of nutrients in lb./acre						
N	53·0	117·2	82·4	70·3	29·5	47·5
P_2O_5	7·7	22·8	11·2	8·6	4·2	6·5
K_2O	37·9	72·0	27·9	19·6	25·2	33·8
CaO	73·7	166·4	95·1	90·8	49·8	161·0

$\underline{C}$ = Cowpeas under study

(c) Wheat (1946-47) and (1947-48)—residual effects

Crop	Wheat (1946-47)		Wheat (1947-48)	
Lysimeter No.	1	2	7	9
Treatment	($OB_1 \cdot C.W$)	($P_1 \cdot B_1 \cdot C.W$)	($OB_2 \cdot C.W.$)	($P_1 \cdot B_2 \cdot C.W$)
Grain per cent composition—				
N	2·86	2·28	2·72	2·37
P_2O_5	0·79	0·57	0·81	0·73
K_2O	1·02	0·90	0·66	0·91
CaO	0·13	0·06	0·097	0·14
Straw per cent composition—				
N	0·41	0·55	0·39	0·49
P_2O_5	0·05	0·07	0·10	0·13
K_2O	2·88	1·68	3·06	2·81
Cao	0·51	0·44	0·64	1·13
Removal of nutrients in lb./acre				
N	94·4	62·5	142·0	165·0
P_2O_5	23·1	14·2	41·7	49·6
K_2O	153·0	67·2	205·6	228·9
Cao	22·6	13·9	41·2	83·5

W = Wheat under study.

TABLE IV

Quality-factors of wheat, viz. weight of 1,000 grains (per cent protein and colour of grain)

Cereal rotation	Wheat (1945-46)—1st crop in cereal rotation—Direct effect of fertilizers				Wheat (1946-47)—3rd crop in cereal rotation residual effects				Wheat (1947-48)—1st crop in 2nd cereal rotation.—Direct effect of fertilizers			
Lysitemer No.	3	4	5	6	3	4	5	6	3	4	5	6
Treatment	O.W.	N.W.	P_1.W	NP_1W	O.W.M.W	NW.M.W.	P1W.M.W	NP1W.M.W.	O.W.	N.W.	P_2·W.	NP_2W.
Weight of 1,000 grains in gm	38·65	35·39	41·85	43·65	29·8	20·13	20·3	35·7	35·7	39·7	38·1	44·8
Percent protein	11·2	15·69	9·81	16·94	10·69	11·62	8·81	10·75	8·9	13·23	11·33	12·45
Colour	Light amber	Dark amber	Ligh amber	Dark amber	Medium amber	Light amber	V.light amber	V.light amber	light amber	Dark amber	V.light amber	light amber

Legume rotation	Wheat (1946-47)—3rd crop in legume rotation		Wheat (14947-48)—3rd crop in legume rotation	
Lysimeter No.	1	2	7	9
Treatment	OB_1.C.W.	P_1B_1·C.W.	OB_2C.W.	P_1B_2.·C.W.
Weight of 1,000 grains in gm	20·7	20·9	45·1	45·84
Percent protein	17·86	14·28	17·01	14·81
Colour	Very dark amber	Very dark amber	Very dark amber	Very dark amber

W—Wheat under study.

Note—1947-48 *Rabi* crop data were statistically analysed. Critical difference for test weight at five per cent level-0·76; at one per cent level-1·0

There was no difference in the nutrient content and removal of nutrients by the *maruwa* crop following wheat crop (1945-46) (Table Ib).

Wheat crop (1946-47) in lysimeter 4 (N. W. M. W.) removed maximum amount of N, P_2O_5, K_2O and CaO (Table Ic). Wheat grain obtained in 1945-46 as a result of direct effect of fertilisation was better in quality than that obtained in 1946-47 where residual effect of fertilisers and cropping was in evidence.

The residual effects of previous manuring and cropping in the cereal rotations were not marked on *maruwa* crop 1947 (lysimeters 3, 4, 5, and 6, Table Id), either in crop composition or removal of nutrients. If the removal of nutrients by all the four crops in the cereal rotation in each treatment was considered, the crops grown in lysimeter 6 (N. P. treatment) removed maximum N, P_2O_5 and CaO. Thus a combination of nitrogenous and phosphatic fertilisers was best to the cereals. Mere application of N alone was not of great advantage.

Legume rotation

Considering the berseem crop (1945-46), (1946-47) and (1947-48) in the legume rotation (Table IIIa) it was observed that phosphatic fertilisation of berseem did not alter the N content, increased the P_2O_5 content and decreased the K_2O content. P_2O_5 application at 200 lb. per acre increased the CaO content. P-treated berseem removed N, P_2O_5, K_2O, and CaO in larger quantities than those removed by untreated berseem. As berseem could meet its nitrogen requirements through the root nodule organisms which fix nitrogen from the atmosphere, the application of P_2O_5 alone, increased the yield, probably due to increased rate of nitrogen fixation by root nodule organisms as a result of this additional nutrient.

Cowpeas (1946) in P-treated lysimeter 2 (Table IIIb) removed more N, P_2O_5, K_2O and CaO than that of untreated berseem lysimeter 1, indicating that the previous phosphatic fertilisation of berseem had a high residual effect for cowpeas.

Considering the wheat crop (1946-47) (Lysimeter 1 and 2, Table IIIc) wheat in P-treated lysimeter 2 gave less yield (*vide* Part I of the paper) and removed less quantity of nutrients than in untreated berseem lysimeter. In 1946-47 *rabi* another set of legume rotation with increased seed rate was started in lysimeters 7 and 9 and it was observed (Tables IIIc and IV) wheat (1947-48) in P-treated berseem rotation lysimeter 9, gave better yield (*vide* Part I of the paper) removed more nutrients and was of better quality as judged by test weight.

Cowpea (1947) fourth crop in legume rotation lysimeters 1 and 2 (Table IIId) from P-treated berseem rotation was richer in nutrient content and removed more nutrients than those removed by cowpeas from untreated berseem rotation. When the seed rate of berseem was increased in (1946-47) phosphatic fertilisation of berseem had no residual effect on cowpea (1947) but as mentioned earlier had pronounced effect on succeeding wheat (1947-48).

Comparison of wheat (1946-47)—3rd crop in legume rotation (lysimeters 1 and 2) to the wheat (1946-47) 3rd crop in cereal rotation (lysimeters 3,4, 5 and 6, Tables IIIc and Ic)

Wheat in legume rotation removed more nutrients and gave grain of better quality (Table IV) as judged by protein content; test weight and general appearance than that in any other treatment in cereal rotation, thus indicating that the soil in legume rotation after removing berseem and cowpeas was at a higher level of fertility than that in cereal rotation after the removal of two crops of wheat and *maruwa*.

Comparison of wheat (1947-48)—3rd crop in legume rotation (lysimeters 7 and 9) to the wheat (1947-48) 1st crop in cereal rotation (lysimeters 3, 4, 5 and 6, Table II)

Wheat grain and straw obtained from legume rotation were richer in N than wheat grain and straw obtained from any of the wheat in cereal rotation receiving direct application of fertilisers. However wheat receiving phosphorus or combined application of nitrogen and phosphorus had higher P_2O_5 content in grain and straw than that of wheat grain and straw obtained from legume rotation. N-treated wheat grain and straw had more CaO content than that of wheat grain and straw obtained from legume rotation.

Wheat in legume rotation removed more nitrogen, phosphorus, potassium and calcium than those removed by any of the treatments in the cereal rotation. The data thus indicate that nutrients were available from the soil in legume rotation in larger quantities than those available in directly fertilized soils in the cereal rotation. Thus by mere introduction of legumes and applying P_2O_5 to legume in the rotation it is at least possible to meet the nitrogen and phosphorus requirements of the wheat crop to the extent to which sulphate of ammonia and superphosphate were applied in these experiments, till some other elements become limiting factors.

Summary

Chemical composition of and removal of nutrients by wheat and berseem crops, as influenced by direct application of nitrogen and phosphorus have been discussed. The influence of these crops and ferilizers treatments on the chemical composition

of and removal of nutrients by the succeeding crops in the two rotations (1) wheat-*maruwa*-wheat-*maruwa* and (2) Berseem-cowpeas-berseem-cowpeas have been studied.

It has been shown that combined application of nitrogen and phosphorus to wheat results in most efficient utilisation of ferilizer material while application of phosphorus alone results in inefficient utilization of fertilizer material.

Introduction of legume in the rotation resulted in making larger quantities of nutrients available to the crops and was further shown that wheat in the legume rotation gave higher yield and removed more nutrients than the wheat receiving direct application of nitrogen and phosphorus. Thus it was possible to meet the nitrogen and phosphorus requirements of wheat crop by introduction of legume in the rotation at least to the extent to which nitrogen and phosphorus were applied. Application of phosphate to berseem in the legume rotation was still more beneficial.

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EXPERIMENTAL TESTS OF MIXED FARMING IN INDIA

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In the reports they presented in 1937, both Sir E. J. Russell and Dr N. C. Wright emphasised the need for extending mixed farming practices in India. The Indian Council of Agricultural Research therefore prepared a scheme for simultaneous investigation and demonstration of mixed farming. This was operated, with local modifications, in four Provinces of undivided India between 1941 and 1946, United Provinces, North West Frontier Province, Central Provinces and Berar, and Sind.

Holdings were to be selected as having reliable and progressive cultivators, either owners or tenants, who would change to mixed farming under direction and advice from the Provincial Department of Agriculture. With each such holding would be associated, as controls, two ordinary arable farms in the same locality. Areas were to be about equal and suitable for management with one pair of bullocks or buffaloes (about 8 acres in U. P., 20 in N. W. F. P., 25-30 in C. P., and 16 in Sind). In each Province, several such 'blocks' of three holdings were to be taken to represent different regions. The mixed farms would acquire two good milch cows or buffaloes (or, in some areas, the equivalent in sheep or goats) ; they would receive a loan to cover the purchase, and grants in aid of initial expenses of maintenance and of conversion of cultivation practices to those appropriate to mixed farming. Careful supervision of cropping and recording (especially on the mixed farms), as well as advice on the conversion of holdings to mixed farming, were to be provided by special staff in addition to the district agricultural staff.

Although the average arable farmer would already have a pair of bullocks and perhaps other livestock (especially in C. P.), the addition of milch cattle should be followed by a change in cropping, the growth of more fodder, and eventually an enrichment of the land. Dairy produce should bring a cash income and also improve the diet of the farmer and his family. The I. C. A. R. scheme provided for the collection of data on crops, income, and expenditure from all farms over a period of several years, from which an assessment of any economic advantage for mixed farming could be made.

Apart from the annual reports on the scheme from the Provinces concerned (which have provided the raw material for this paper), the only publications discussing the results of this investigation appear to be those of Ibne Ali [1950] and Raheja and Obhrai [1953]. Ibne Ali was concerned only with U. P.; he made useful comments on the advantages of mixed farming, but gave no thought to the

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possibility that anything other than the practice of mixed farming could explain the extra profits on these holdings. Raheja and Obhrai unfortunately did not have access to all the annual reports and introduced a number of mis-statements because they were not aware of serious deviations from the original plan in C. P. and Sind. Moreover, they also uncritically assumed that all differences in profits and yields between mixed farms and controls were the result of the introduction of mixed farming.

1. Details from the Provinces

United Provinces

Six double blocks, each of two mixed farming and four control holdings, were established and observed for five years. Each holding had two working bullocks, and areas ranged from 3 to 12 acres. In four blocks, each mixed farm added two Murree buffaloes; in the fifth, two Murree buffaloes and a Hissar cow; and in the sixth, two Sahiwal cows. Pedigree bulls were available. For the first year, the control farms in the Meerut block also had milch animals, but income and expenditure relating to them have been excluded. The chief crops grown were sugarcane, *rabi* wheat and gram, and *kharif* maize and rice. The mixed farms produced enough fodder for the additional livestock, and probably most of the farmyard manure went to sugarcane.

North West Frontier Province

This Province had eight blocks, each of one mixed and two control farms; records are available only for three years. The livestock supplied were: two buffaloes at each of two farms, one cow and one buffalo at another, three cows at three farms, 16 goats at the seventh, and 17 sheep (replaced by two cows, after heavy losses from liver fluke) at the eighth. Areas of holdings ranged from 5 to 12 acres. The crops included all the major cereals, gram and other legumes, sugarcane, cotton, tobacco, vegetables, and fodder.

Central Provinces (Rice tract)

Four blocks, each of one mixed and two control farms, were recorded for five years. Each mixed farm had two Berari buffaloes in addition to the normal working bullocks and other livestock. Areas of holdings ranged from 13 to 17 acres. Intensive cropping with rice, using legumes as catch crops, was practised. The mixed farms, however, failed to maintain their stock by increasing fodder at the expense of cash crops; in fact, they bought fodder and also grazed stock on leased land.

On some of the mixed farms, successful results in the first year or two and enthusiasm for the demonstration aspect of the scheme led to the purchase of more dairy animals. Maintenance costs and direct profits from these were supposed to be eliminated from all the accounts of income and expenditure, but of course their influence on cropping and yields is necessarily included in the records.

Central Provinces (*Cotton tract*)

Four blocks of the same type as in the rice tract were recorded for five years, with two Berari buffaloes on each mixed farm. Areas were between 19 and 34 acres. One mixed farm was badly situated on poor eroded soil, unlike the corresponding controls. Cropping was similar to that of the rice tract, except for the change of major crop, but was less intensive. Little fodder was grown, stock being maintained largely on *jowar* straw and cotton seed.

As in the rice tract, some mixed farms added more dairy animals to their stock, and the same attempt at elimination of their effects was made.

Sind

Work in Sind differed considerably from that in other Provinces, the comparison made being between 'ordinary' and 'improved' farming methods, both with mixed farming. Other purely arable farms were supposed to be kept under observation as controls, but records from them were too scanty to be useful. Only two complete years were recorded for three blocks of one mixed farm and one control each, and the records were in many respects inadequate. Results from Sind are therefore not included in this report.

2. The records

For all mixed farms, cropping plans were recommended by the supervisory staff, but quite considerable deviations occurred. The actual cropping of every part of each holding (mixed and control) was recorded, and wherever possible figures for yields were obtained. No records were kept of what areas were irrigated.

The special staff were responsible for recording income and expenditure on a standard basis for every holding; information was obtained by regular inquiry from the farmers, and items for crops and livestock were kept separate. Figures for income were based on current values for crop and animal products. The following were excluded from income: straw, chaff, and green fodder fed to the extra stock; produce used as wages; produce saved for seed. Crop and livestock products used by the family, however, were included as income, as also were earnings from the hire of working animals. For processed products (*gur*, *ghee*, etc.), only the value of the raw materials was recorded as income.

Crop expenditure included land revenue, seed, irrigation charges, manure bought off the farm, labour, maintenance of bullocks, etc. Production costs for fodder were divided between bullocks and milch animals in proportion to their consumption, only the latter being regarded as expenditure on livestock for the purposes of this investigation. Other expenditure on milch animals includes concentrates purchased, veterinary charges, and allowances for depreciation. Family labour was not treated as an item of expenditure.

The three preceding paragraphs are based upon the instructions prepared by the I. C. A. R. The detailed reports from U. P. show that the standard method of recording was followed there; in N. W. F. P. and C. P., much less information

on how the accounts were built up is available, and the extent of any deviation from the standard is unknown. In N. W. F. P., expenditure was not reported separately for crops and livestock.

3. Income, expenditure, and profits

Table I shows the average net profits per acre, obtained as differences between average recorded income and average recorded expenditure, year by year in each Province for the two types of holding.* The heading 'livestock' relates only to the additional stock supplied to mixed farms. The grants to cultivators on mixed farms did not enter into the accounting, so that the profits shown are higher than the true profits of operation. The maximum grant was Rs. 360 spread over five years: Rs. 40 per annum to cover repayment of the initial loan for purchase of stock, Rs. 20 per annum towards maintenance of stock, and Rs. 20 per annum for three years towards the cost of new cultivations. On an eight acre holding, typical of the mixed farms in U. P. and N. W. F. P., this would amount to Rs. 10 per acre for three years followed by Rs. 8 per acre for two, and so is roughly equal to the nominal profit attributed to livestock in Table I.

The table apparently indicates great superiority for mixed farming, especially in U. P. and N. W. F. P.; study of the detailed records leaves no doubt that differences between profits on mixed and control farms were consistent and real. As will be seen from the subsequent discussion, however, examination of all the evidence indicates that the apparent increase in profits on the mixed farms is due, entirely or very largely, to causes other than the change in farming practice.

Although the increase from year to year in the advantage for mixed farming suggested by U. P. and N. W. F. P. would be consistent with a steadily increasing fertility and productivity, a gain of Rs. 30—50 per acre in the first or second year can scarcely be attributed to this cause. Tables II and III, the figures for expenditure and income from which Table I was calculated, throw further light on this. The cost of production per acre for crops on the mixed farms was much the same as for the controls; inclusion of the livestock costs naturally makes the total for the mixed farms the higher (Table II). Incomes, however, differed to an even greater extent on the two types of farm (Table III). In U. P., the additional profit even in the early years came largely from crops, the small amount attributed directly to livestock being practically balanced by the special grants to the cultivators; Table III suggests that the same was true in N. W. F. P. Mixed farming can benefit crops only through the improvement of soil fertility by rotational fodder cropping and by an increased supply of farmyard manure. The first is necessarily a long term effect,

* For all tables, in order to avoid biased comparisons, every quantity tabulated was first calculated for each farm, then averaged for each type of farm (mixed or control) in each block of a Province, and finally averaged over all blocks in the Province. In one or two instances, the averaging was complicated by gaps in the data, (e. g. omission of records of crop yields at certain farms in some years, or failure to classify income as from crops or livestock); adjustments have been made in accordance with standard statistical practices, but the need for these was sufficiently rare for the final summaries to be little affected by the precise method of adjustment. In order to allow for differences in sizes of holdings, all items of income and expenditure have been expressed in rupees per acre of holding.

TABLE I

Net profit per acre (rupees)

Province		1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
		Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
U.P.	C	19		94		124		111		?		(98)	
	L	5		1		22		10		?		(13)	
	T	24	18	95	62	146	68	121	46	169	69	111	53
N.W.F.P.	T	—	—	107	54	146	63	177	77	—	—	143	65
C.P. (r)	C	22		45		49		51		54		50	
	L	?		10		9		8		12		10	
	T	?	?	55	25	58	33	59	26	66	32	60	29
C.P. (c)	C	17		25		31		22		25		24	
	L	2		4		5		9		12		7	
	T	19	15	29	30	36	28	31	16	37	18	31	21

In this and subsequent tables, C = crops, L = livestock, T = total; (r) = rice tract, (c) = cotton tract.
For U.P. no division for crops and livestock was recorded in 1945-46; the means are based on subtraction of Table II from Table III.
For C.P. (r), 1941-42 data are incomplete and have been omitted from the means.

TABLE II

Cost of production per acre (rupees)

Province		1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
		Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
U. P.	C	38		44		54		63		?		(51)	
	L	14		22		28		28		?		(24)	
	T	52	39	66	44	82	65	91	71	86	68	75	57
N. W. F. P.	T	—	—	19	10	20	12	28	21	—	—	22	14
C. P. (r)	C	14		17		24		26		38		26	
	L	?		6		6		9		8		7	
	T	?	?	23	13	30	16	35	24	46	30	33	21
C. P. (c)	C	10		20		24		25		28		21	
	L	5		6		5		7		4		5	
	T	15	9	26	13	29	22	32	26	32	23	26	19

For U.P., no division for crops and livestock was recorded in 1945-46; the proportion of the means is based on the first four years only.
For C. P. (r), 1941-42 data are incomplete and have been omitted from the means.

TABLE III

Income per acre (rupees)

Province		1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
		Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
U. P.	C	57		138		178		174		199		149	
	L	19		23		50		38		56		37	
	T	76	57	161	106	228	133	212	117	255	137	186	110
N. W. F. P.	C	—		92		128		174		—		131	
	L	—		34		38		31		—		34	
	T	—	—	126	64	166	75	205	98	—	—	165	79
C. P. (r)	C	36		62		73		77		92		76	
	L	?		16		15		17		20		17	
	T	?	?	78	38	88	49	94	50	112	62	93	50
C. P. (c)	C	27		45		55		47		53		45	
	L	7		10		10		16		16		12	
	T	34	24	55	43	65	50	63	42	69	41	57	40

For C. P. (r), 1941-42 data are incomplete and have been omitted from the means.

since only a small acreage of fodder legumes will be grown in one year. With regard to the second, a pair of cows or buffaloes should produce about 15 tons of dung per annum (green weight), of which 80 per cent is moisture lost in drying. Thus, after allowance for some losses, the additional livestock on the mixed farms could have provided at most two to three tons of farmyard manure, quite insufficient to produce any dramatic improvement in the fertility of an 8-10 acre holding in two years.

In the two tracts of C. P., the difference in profit per acre between the two types of holding was smaller, and the tendency to increase was less marked. As explained in Section 2, true mixed farming (involving growth of fodder crops, especially legumes, for the maintenance of high quality stock and the improvement of the land) was not practised : purchase of fodder and grazing on leased land to a great extent defeated the purpose of the investigation. Again most of the profit was derived from crops. The argument of the previous paragraph would apply with equal force, but need scarcely be invoked here since the data have little relevance to the study of true mixed farming.

4. Intensity of cropping

Further evidence on the interpretation of Table I is provided by consideration of the intensity of cropping. As a measure of this, the total acreage of crops (excluding green manure) on a holding in each year was expressed as a percentage of the area of the holding* and averaged (Table IV). Except in the cotton tract of C. P., cropping was considerably more intensive on the mixed farms. A new percentage intensity (Table V), excluding all fodder crops, shows that in U. P. the more intensive cropping was entirely due to the growth of fodder but that in C. P. and N. W. F. P. this was not so. Moreover, the difference between mixed and control farms was as great in the early years as later, and the intensity of cropping on mixed farms did not show the increase from year to year that would be expected if steady improvement in fertility made possible fuller use of the land. The intention that the cropping plan should be modified only by the needs of the added livestock was clearly not adhered to. Indeed, the records show that very little fodder was grown in C. P. In N. W. F. P., food shortages and the army's demand for vegetables led some farmers to seek large returns from small acreages of certain cash crops. The tendency to take advantage of current needs for cash crops was naturally particularly evident amongst the cultivators of mixed farms, who, as stated in the introduction were selected as being ' progressive '. Profits from these crops could be credited to mixed farming only if farmyard manure were essential to their cultivation, and in any case the high prices realised were a consequence of exceptional economic conditions.

5. Yields

Fairly numerous records of yields for the major crops, summarised in Table VI, give no support to any belief in increasing fertility of land under mixed farming. Yields were almost invariably higher on the mixed farms, but the differences are as

* Some land carried two crops in a year, so that this percentage could exceed 100. Crops that failed to germinate, or for other reasons did not come to harvest were included.

TABLE IV

Intensity of cropping (per cent of size of holding)

Province	1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
U. P.	149	?	154	?	145	132	146	120	129	110	140	120
N. W. F. P.	—	—	164	113	175	106	160	136	—	—	166	118
C. P. (r)	150	131	161	124	166	136	158	139	156	139	158	134
C. P. (c)	98	92	98	94	98	95	98	94	99	95	98	94

For U. P., no data were available on the control farms in 1941-42 and 1942-43; the means relate to the last three years only.

TABLE V

Intensity of cropping, excluding fodder (per cent of size of holding)

Province	1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
U. P.	124	?	117	?	114	132	122	120	106	110	114	121
N. W. F. P.	—	—	126	103	137	98	144	131	—	—	136	111
C. P. (r)	148	131	149	124	158	136	156	139	156	139	153	134
C. P. (c)	96	92	98	94	98	95	98	94	99	95	98	94

For U. P., no data were available on the control farms in 1941-42 and 1942-43; the means relate to the last three years only.

TABLE VI

Crop yields (maunds per acre)

Crop and Province		1941-42		1942-43		1943-44		1944-45		1945-46		Mean	
		Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control	Mixed	Control
Paddy	U. P.	?	?	?	?	10·9	7·7	9·4	6·5	13·4	10·5	11·2	8·2
	C. P. (*r*)	10·9	8·9	12·6	11·0	14·8	13·8	14·2	12·0	14·4	12·7	13·4	11·7
Wheat	U. P.	?	?	?	?	13·6	9·2	14·7	12·3	14·4	10·9	14·2	10·8
	N. W. F. P.	—	—	7·8	7·7	6·4	5·4	9·9	7·9	—	—	8·0	7·0
Maize	N. W. F. P.	—	—	13·5	10·8	15·4	9·1	13·5	8·6	—	—	14·1	9·5
Jowar	C. P. (*c*)	5·8	7·3	6·5	6·3	6·7	6·2	5·9	6·0	7·6	7·6	6·5	6·7
Gram	U. P.	?	?	?	?	12·3	8·9	8·0	5·9	9·4	7·4	9·9	7·4
Sugarcane	U. P.	?	?	?	?	570	380	490	390	540	400	530	390
Cotton	C. P. (*c*)	5·2	4·3	3·5	2·3	3·8	4·3	2·6	2·6	3·2	1·9	3·7	3·1

great in the early years as later, so suggesting that the primary causes were initial differences between farms assigned to 'mixed' and 'control' series. For example, in three successive seasons in U. P., the paddy yields on the mixed farms exceeded those on the controls by 3·2, 2·9, 2·9 maunds per acre respectively; the corresponding differences for wheat are 4·4, 2·4, 3·5 maunds per acre. The wheat and maize yields for N. W. F. P. may seem to show increasing differences between the two types of holding, but inspection of the figures for individual blocks shows the absence of any consistent trend.

The increasing difference in profits in favour of the mixed farms in U. P. and N. W. F. P. must be attributed to changes to more profitable crops rather than to improvement in the yields of the staple crops.

6. Discussion

Enough has been said already to show that the differences between mixed farms and controls in respect of profits and yields in the three Provinces were not at all what would be expected from the slow improvement of holdings consequent upon the introduction of mixed farming. In U. P. and N. W. F. P., the differences were too large at the start for this 'obvious' interpretation to be tenable, and in C. P. mixed farming was not in fact practised.

Certain major flaws in the experiment may explain the results. Holdings for mixed farms were admittedly chosen because of good management and suitability to act as demonstrations for their neighbourhoods; they were, therefore, almost certainly initially in better conditions. Moreover, supervision of the mixed farms and close observation of progress must have necessitated much more frequent visits by supervisory staff from the Departments of Agriculture than the control farms received. This tendency would be present even if the investigation had been purely experimental, but would be greatly strengthened by the wish to maintain good demonstrations. Not only would these farmers thus have more opportunities for receiving advice on crop and animal husbandry than would the controls, but they would be more capable of benefiting from it.

To assess the extent to which these factors contributed to the extra profits on the mixed farms is impossible. If accounts and other records had been kept for a preliminary year, on all holdings, before the introduction of mixed farming, they would have given some information on initial differences. The holdings in C. P. were subject to the factors of selection and advice favouring the mixed farms just as in U. P. and N. W. F. P., although true mixed farming was not practised; the results are of no use for estimating the magnitudes of the biases produced elsewhere, however, since these biases would vary from Province to Province.

Thus the true explanation of the differences found between records from the mixed farms and those from the controls appears most probably to lie in factors inherent in the planning and conduct of the investigation and not in mixed farming itself. To say this is in no sense to deny that mixed farming can be beneficial. Benefits to soil fertility, and thereby to farm profits, cannot appear quickly and would

be unlikely to be demonstrated by an investigation of this character in three or four years. No attempt was made to determine any improvement in the health of cultivators and their families resulting from increased consumption of dairy products.

7. An improved investigation

A more satisfactory study of the economics of mixed farming would require three major improvements over the scheme described here. First, it should be free from any notion of demonstrating a preconceived opinion that mixed farming is advantageous: within the framework of the scheme, the mixed farming practised could be regarded also as a demonstration to neighbouring cultivators of how to introduce milch animals into an arable farm, but to start with an assumption that this is a better method of farming may vitiate the attempt to assess its value.

Secondly, three types of holding should be compared instead of two: those having no interference with their normal arable routine, those changing to mixed farming under advice from their Department of Agriculture, and those having similar close supervision and advice on crops but without additional livestock.

Thirdly, in agreement with experience in all other types of agricultural research, the only true safeguard against initial and intrinsic differences between holdings and differences in farming skill should be employed: sets of three roughly similar holdings in a locality should be chosen for study, and from each such set one should be selected *strictly at random* for each of the three ' treatments '.

The experiment should of course be restricted to regions in which mixed farming is practicable. Every effort should then be made to secure that each participating State or other authority conforms to the standard pattern, and major deviations such as those that occurred in C. P. should be regarded as falling entirely outside the investigation. Additions to the livestock beyond those needed for the experiment should be avoided, at least for the first few years. Recording would need to be just as full as for the earlier scheme, but, in the light of experience gained from the conduct and analysis of this, fresh thought should be given to the ideal form of accounting. For example, the manner of accounting for family labour and family, and the recording of expenditure and income appropriate to livestock and crops separately need careful examination. Special subsidies and grants to cultivators also need more thorough accounting than in the past. Attempts should be made to secure, from all holdings, some measure of the quantities of farmyard manure produced and the crops on which it was used. To maintain all these records for one complete year before the experiment proper began would give further interesting information, but this is not essential. The experiment should continue for at least five years.

8. Summary

The I. C. A. R. mixed farming investigations, conducted in three Provinces between 1941 and 1946, were intended to evaluate the economic advantages of mixed farms relative to purely arable farms in the same locality. The records

certainly show greater net profits and higher yields on the mixed farms, but examination of the data does not support the attribution of these differences to increased fertility and other consequences of mixed farming.

The mixed farms were also intended as demonstration holdings; they were, therefore, specially selected as having progressive cultivators and they received extensive help from the Provincial Departments of Agriculture. Initial differences in the fertility and management of the two types of holding, together with the extra advice the mixed farms received, appear likely to be responsible for all or most of the differences in profits and yields. Moreover, in one Province true mixed farming was not seriously attempted, and in another exceptional economic conditions disturbed the figures by permitting large profits from vegetables and other cash crops.

This paper does not purport to disprove the existence of benefits from mixed farming, but only to demonstrate that the investigation analysed does not provide any proof. Suggestions are made for avoiding past flaws and mistakes in any future experimentation on the same problem.

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MANURIAL EXPERIMENTS WITH THE POOVAN BANANA (I)

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The importance of nitrogen in the nutrition of the banana plant has been widely recognised. Croucher and Mitchel [1940] in their investigations with the Gros Michel banana, have shown that increase in yield could be produced only by the application of nitrogen and not by the application of potash and phosphate in soils which are rich in available potash and phosphoric acid. Sand culture trials by Japanese workers have indicated that nitrogen is the most important nutrient for the banana crop. Analysis of Cavendish bananas grown under pot culture has led to the inference that both nitrogen and potash requirements of the crop are heavy [Fawcett, 1921]. Wood in Trinidad has recorded increased yield in bananas by the application of farm yard manure and potash [Wood, 1939]. Heavy applications of nitrogenous fertilizers are given to the crop in the commercially developed banana regions of the world. In Jamaica the total quantity of nitrogen applied per clump in six weekly applications of ammonium sulphate is as much as one pound. In Queensland, Australia, 8 lb. of manure mixture per stool applied in three doses to supply not less than one pound nitrogen per clump and in certain areas, in addition, application of 2 oz. ammonium sulphate per plant every six weeks are the manurial practices followed [Richards, 1951]. Dhareshwar [1952] has mentioned that for the Basrai bananas under Deccan conditions, a basic dose of 80 lb. farm yard manure per stool, to supply 0·4 lb. nitrogen gave the maximum yield and income. Gandhi [1952] has detailed a total dose of 15 lb. of castor cake per plant supplying about 0·80 lb. of nitrogen, for the Bombay Green banana variety, as top dressing in three doses in the Bassein area of Bombay State. The same author has recorded that for one acre of dwarf bananas grown in East Khandesh 328 lb. of nitrogen per acre is applied as farm yard manure and groundnut cake. The manuring practice followed at the Agricultural Research Station, Samalkot, was the application of 20 cart loads of cattle manure and 1000 lb. of ammonium sulphate per acre [Naik, 1948]. At Gangavaram in East Godavary district, the present practice is to apply two baskets of cattle manure weighing 50 lb. and $1\frac{1}{2}$ lb. ammonium sulphate per plant in two doses. This works out to a little over $\frac{1}{2}$ lb. nitrogen per plant. Jacob [1951] recommends two doses each of two baskets of cattle manure or $1\frac{1}{2}$ lb. powdered oil cake or 2 lb. tannery refuse. In the Kattuputhur area of Thiruchirappally district, the following manuring programme is followed over extensive tracts of wet land bananas:—

(i) Within a few days after planting, 20 lb. of compost per plant is applied and earthed up.

(ii) Three months after planting two bags (448 lb.) of ammonium sulphate per acre which works out to $\frac{1}{2}$ lb. per plant are applied.

(iii) Five months after planting nine bags (1440 lb.) of groundnut cake per acre which nearly works out to $1\frac{1}{2}$ lb. cake per plant are applied.

(iv) Seven months after planting two bags of ammonium sulphate or five bags (400 lb.) of patented manure mixtures per acre are applied.

The manurial practices detailed above as well as the dosages of different kinds of manures adopted are observed to vary from place to place. With the object of finding out the value of different manurial practices by the application of the most commonly used forms of nitrogenous fertilizers, viz., cattle manure, groundnut cake and ammonium sulphate either alone or as a mixture of any two and also to ascertain in general how far the addition of potash, or potash and phosphoric acid would contribute to yield, the present manurial trial was laid out in the wet land area of the Central Banana Research Station, Aduthurai, which is typical of the deltaic soil of the Tanjore District.

MATERIAL AND METHODS

The Poovan variety, the outstanding commercial variety of this tract was utilised for the trial. Uniform-sized, four months old suckers were planted on 8 March 1951, under the eight treatments detailed below, adopting a randomised lay-out replicated four times. A guard row of the same variety was provided for each plot which contained 16 experimental plants and 20 non-experimental plants all round. The plants in the guard row received the same treatment as for the plants enclosed. A spacing of eight feet was given to all the plants. A basal dressing of 25 lb. cattle manure per plant was given to all the plants.

Treatments

There were eight treatments as detailed below:

A. Control (Basal dressing of 25 lb. cattle manure only).

B. Cattle manure to supply $\frac{1}{2}$ lb. nitrogen per plant.

C. Cattle manure to supply $\frac{1}{4}$ lb. nitrogen plus ammonium sulphate to supply $\frac{1}{4}$ lb. nitrogen per plant.

D. Cattle manure to supply $\frac{1}{4}$ lb. nitrogen plus groundnut cake to supply $\frac{1}{4}$ lb. nitrogen per plant.

E. Groundnut cake to supply $\frac{1}{4}$ lb. nitrogen plus ammonium sulphate to supply $\frac{1}{4}$ lb. nitrogen per plant.

F. Cattle manure to supply $\frac{1}{2}$ lb. nitrogen plus superphosphate to supply $\frac{1}{2}$ lb. phosphoric acid per plant.

G. Cattle manure to supply $\frac{1}{2}$ lb. nitrogen plus potassium sulphate to supply $\frac{1}{2}$ lb. potash per plant.

H. Cattle manure to supply $\frac{1}{2}$ lb. nitrogen plus superphosphate to supply $\frac{1}{2}$ lb. phosphate plus potassium sulphate to supply $\frac{1}{2}$ lb. potash per plant.

NOTE. The doses of manures detailed under treatments B to H are in addition to the basal dressing of 25 lb. cattle manure per plant.

Two feet cube pits were dug one month prior to planting and one basket (25 lb.) of well rotten and powdery cattle manure applied. The manure was mixed with the top soil and the pits covered. Four months old sword suckers of uniform size

were planted scooping out sufficient soil from the centre of the pit to bury the rhizome. The soil around the plants was pressed well to hold the suckers firmly and erect. The plants were pot-watered at a uniform rate at frequent intervals for a period of about three months, till channel water was available for irrigation. The suckers commenced fresh growth by the middle of May. During the second fortnight of May, heavy precipitations of rain amounting to 2·28 inches were received. As programmed, half the quantity of the manurial doses was applied after the receipt of rains three months after planting. The manures were applied in shallow basins formed round plants to a distance of two feet all round and covered. A shallow digging was given to the entire area following the manuring operations. The area was irrigated once in June 1951. This was followed by formation of uniform-sized beds with four plants, identically placed, per bed. Each bed was demarcated all round by drains two feet in width and a foot in depth. The soil excavated from the drains was used in earthening up the plants. Channel water for irrigation was received by the middle of July. Desuckering operations were systematically done from the second fortnight of August onwards till the emergence of the inflorescence of each plant, from which stage onwards one flower was allowed per plant. The application of the second half of the manurial doses was completed in September 1951, five months after planting. The method of application was similar to the previous one. Only the size of the basins was increased by about one foot diameter. The drainage channels were deepened and earthing up was done to all the plants in December. The area was irrigated once every month in April, May and June 1952. All the plots were dug, channels cleaned and deepened and plants earthed up before the supply of channel water for irrigation in July 1952.

Growth records, flowering and yield data

Growth records of height, girth and leaf counts were recorded, three months after planting onwards every month up to the date of flowering. There were no significant differences between the treatments in girth and number of leaves produced throughout the period of growth. With regard to height measurements, the differences were insignificant for the first seven months after planting. Analysis of height records taken during the eight months showed significant differences between treatments as detailed in Table I. The growth measurements could not be compared after November as flowering commenced during November 1951.

TABLE 1

Analysis of height measurements recorded on 8 November 1951

Particulars	Treatments							
	A	B	C	D	E	F	G	H
Mean height in cm.	146·6	173·6	240·9	208·5	213·5	152·6	140·1	153·7

Standard error—13·9
Critical difference—28·9 (P—0·05)
Z test—Satisfied
Conclusion : C E D B H F A G

The above conclusion indicates that the treatment in which cattle manure and ammonium sulphate are applied each to supply $\frac{1}{4}$ lb. nitrogen per plant is leading the rest in height measurement except the treatment in which groundnut cake and ammonium sulpnate are given to supply the same quantity of nitrogen equally. It may also be noted that the application of half the quantity of nitrogen as ammonium sulphate or groundnut cake with the other half as cattle manure has resulted in recording better height measurements than when the whole of the nitrogen on half pound level is applied as cattle manure.

Flowering commenced on 20 November 1951 and continued up to the end of August 1952. All the plants under treatment 'C' flowered before 28 February 1952, within 356 days after planting. Within this period only thirty per cent of the rest of the plants have flowered. Harvests commenced on 20 February, 1952 and continued up to 25 November 1952. The mean duration in days of the plants under the different treatments, from planting to harvest are given in Table II.

TABLE II

Mean duration in days of plants under different treatments

Treatment	Duration in days	Treatment	Duration in days
A	537	D	409
B	492	E	534
C	382	G	544
D	411	H	531

The analysis of yield data are presented in Table III.

TABLE III

Analysis of yield data

Treatment	A	B	C	D	E	F	G	H
Mean bunch weight in lb.	16·1	20·0	33·9	29·2	30·0	16·2	18·3	16·6

Standard error—1·6
Z test—Satisfied
Critical difference—3·4 (P—0·05)
Conclusion : C E D B G H F A

The above analysis shows that the highest mean bunch weight of 33·9 lb. given by treatment 'C' cattle manure to supply $\frac{1}{4}$ lb. nitrogen plus ammonium sulphate to supply $\frac{1}{4}$ lb. nitrogen per plant, is significantly superior to the rest. Treatments

'E' and 'D' in which groundnut cake replaces cattle manure to supply equal quantity of nitrogen, are nearly equal to each other in effect. Treatment 'B' cattle manure to supply ½ lb. nitrogen per plant is the next best with a mean bunch weight of 20 lb. The additions of potash in the form of potassium sulphate or phosphate as superphosphate or both have not shown any response.

Discussion

The soil analysis, immediately before the commencement of the manurial trial has revealed that the soil is fairly well supplied with lime, nitrogen, total and available phosphoric acid and total potash contents. The soil of the locality is known to have been formed, by silt deposits of the Cauvery delta and as such should be considered as rich. The soil has responded well to the application of nitrogen contained in the treatments 'C', 'D' and 'E'. There was no response to phosphate application as the soil is rich in total and available phosphate. Though the soil is rich in total potash, it is poor in available potash. Lehr [1941] in his investigations on plant nutrition has shown that one of the decisive factors for yields is the exact proportions of the cations Ca and K and not their absolute quantities available. It is possible, that in the soil under discussion the analysis of which has shown that it is fairly well supplied with lime and potash, that the proportion of Ca and K is satisfactory as not to show sufficient response to the application of potash.

An interesting inference noted from the data under duration of the plants under different treatments, is that this period, for the same banana variety, Poovan, planted under identical conditions is within a wide range of variation when the plants are grown under different manurial treatments. It is also striking that the mean duration in days of plants under the treatments 'C', 'E', 'D' and 'B' follows the same sequence of yield figures under the respective treatments. The inevitable conclusion is that the best manuring practice hastens growth and induces earliness in flowering and fruiting in addition to enhancing crop size. In a crop like banana this is of additional importance in agricultural practice as earlier plant and ratoon crops could be taken in the programme of rotation.

The yield data is also educative with regard to an important principle governing manuring of crops, viz. that crop yields do not entirely depend on equivalent quantities of the requisite plant food, like nitrogen, applied by nitrogenous fertilizers, but yields distinctly show a preference to certain composition of such fertilizers. The most beneficial combination in the present experiment is given by cattle manure and ammonium sulphate, each to supply ¼ lb. nitrogen per plant. The value of a nitrogenous fertilizer for the banana is therefore not to be determined by its nitrogen contents alone but also with the consideration of the form in which that element is present. Wallace [1947] has established that organic matter has a general effect of conserving and regulating the supply of nutrients. Considering the fact that nitrogenous fertilizers like ammonium sulphate are effective only for short periods, the importance of cattle manure in regulating the availability of this foremost nutrient cannot be over emphasised. Croucher and Mitchel [1940] have reported that ammonium sulphate by maintaining a high concentration of nitrate in the soil helps the

banana plant to grow well at an uniform rate. To maintain a continuous supply of nitrate ions frequent applications of this chemical manure are indicated. How far the admixture of cattle manure or other organic manure will contribute to curtail the number of such applications and to what limit these fertilizers could be applied to secure maximum profits from this crop will be suitable subjects for a separate investigation.

Another point worthy of note is that in localities where cattle manure is available in sufficient quantities, it is comparatively a cheaper source of nitrogen than cake or ammonium sulphate. From the point of view of economic fertilizing also the combination of cattle manure and ammonium sulphate is to be preferred to the other two. The cost of manuring for the treatments C, D, and E works out to Re. 0-11-0, Re. 0-12-6 and Re. 0-11-6 per plant respectively.

Summary

This paper deals with a field trial on the manuring of bananas to find out the value of different manurial practices by the application of cattle manure, groundnut cake and ammonium sulphate as a mixture of any two as compared to cattle manure alone and to ascertain in general how far the addition of potash or phosphoric acid or both would contribute to yield. The results show that the best manurial dose per plant is given by the treatment in which ¼ lb. nitrogen is applied as cattle manure and ¼ lb. as ammonium sulphate in two doses, the first dose three months after planting and the second five months after planting. These applications are in addition to the basal dose of 25 lb. cattle manure per plant applied prior to planting. The substitution of groundnut cake to supply ¼ lb. nitrogen either to replace cattle manure or ammonium sulphate has given the next best results which are nearly identical in value. Under the heavy clay wet land soils of Aduthurai which are typical of the Tanjore delta, there is no response to the addition of potash or phosphoric acid.

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ANATOMICAL STUDIES IN RELATION TO VERNALISATION

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(With two text-figures and Plates IX-XI)

It has been observed by a large number of investigators [Wilton and Roberts, 1936; Wilton, 1938 and Dutta, 1945] that the cambial activity in the stems of annual plants is considerably slowed down with the onset of flowering and by the time pods develop, the cambium is completely transformed into xylem and phloem elements. In stems of plants artificially induced to bear flowers through suitable photoperiodic treatment, Struckmeyer [1941] even observed signs of decreasing activity of the cambium some days before the flower buds were visible. The same author has also recorded that if the plant, after an incomplete photoperiodic induction, is taken back to the original light conditions, the cambium regains its activity.

Murneek [1948 a, b] observed that in soyabean plants subjected to short photoperiodic treatment, the shoot tip changes from a dome-shaped (vegetative) to a plateau-shaped (reproductive) condition. Recently Popham and Chan [1952] have demonstrated that the varieties of chrysanthemum, studied by them when subjected to short photoperiods for six days, showed cessation of cell division and cell enlargement in the vegetative shoot apex and these were the first indications of the onset of the flowering condition. These authors also came to the conclusion that the physiological alterations must have begun to occur in the vegetative apex almost immediately following exposure of the plant to the first short photoperiod.

Though our knowledge of the changes in the internal morphology of plants induced to flower early through photoperiodic treatment is thus quite comprehensive, there is hardly any observation along similar lines on plants raised from vernalised seeds and the present investigation has been undertaken to collect data on the same.

Materials and methods

The following plants which are well known to respond to vernalisation treatment [Sen and Chakravarti, 1939; Sen, 1940; Pal and Murti, 1942 and Sukla, 1949] were selected:

Brassica campestris Linn., T. 102; *Eruca sativa* Lam., Local; *Lens esculenta* Moench, T. 4315-7; *Cicer arietinum* Linn., T. 4; *Lathyrus odoratus* Linn., Sutton's mixed; *Pisum sativum* Linn., I. P. 29; *Linum usitatissimum* Linn., Strain 477-3/2.

Cereals had to be excluded, firstly because the vernalisation response of Indian trains of wheat varies from year to year [Sen and Chakravarti, 1945 a, b; 1946]

and secondly so few of them have stems suitable for sampling when in nonflowering state [Roberts and Struckmeyer, 1948]. Comparative study from germination onwards has been confined to mustard only and the rest of the plant materials have been used for collecting data on mature stem structures.

Seeds of the above-mentioned varieties were soaked in tap water for 6-8 hours and hung in *khadi* bags from the lid of an ice-box for a period of 3-4 weeks. Concentrated KOH solution [Sen and Chakravarti, 1942] was used to absorb CO_2. One filling of ice daily was sufficient to maintain the temperature between 4-8°C.

There were 16 randomised pots for each strain divided equally between the two treatments. Thinning was carried out several times, finally allowing 5-7 plants to remain in each pot. Samples for anatomical study were drawn from five pots and three were left undisturbed for the collection of data on anthesis. Statistical significance of the difference in the vegetative cycle* of vernalised and control plants† was determined by 't' test.

Materials collected were : (i) Normal seeds soaked for six hours ; (ii) shoot tips and radicles of seedlings raised from treated and untreated seeds for the ages of 1-7 days at an interval of 24 hours and then on the 9th day ; (iii) shoot tips of adult plants 15 and 22 days old and (iv) the fourth elongated internode below the stem tip at the vegetative stage and the second internode below the first flower or the terminal inflorescence at the reproductive one [Wilton and Roberts, 1936]. They were all fixed in formaline-acetic alcohol, the proportion being 5 : 5 : 90 for seeds, seedlings and shoot apices and 6 : 2 : 100 for the rest.

Mature stems were passed through the normal butyl alcohol series and the rest through the xylol one and embedded in paraffin. The former were sectioned 15-18 μ and the latter 13 μ thick. Sections from at least three different specimens were obtained for each stage to have an idea of their average condition.

Most of the staining for vascular differentiation and apical meristem were carried out with iron-alum-haematoxylin followed by safranin [Esau, 1941] and a few with aqueous crystal violet and erythrosin in clove oil. The latter combination was also used for mature stem anatomy, as crystal violet has been found to be more suitable than any other stain for lignification. With an advance in the age of the plants, the intensity of crystal violet on lignified tissues appears to be progressively marked. Photomicrographs of mature stem structures, however, were taken from sections stained with cotton red [Wilton and Roberts, 1936].

Observations

Vernalisation response

Date of anthesis for vernalised and control plants are presented in Table I, a perusal of which would clearly indicate that in all the strains used for the present study, vernalised plants flower significantly earlier than their corresponding controls.

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* Vegetative cycle means number of days taken from germination to anthesis.

† Vernalised and control plants indicate plants raised from treated and normal seeds respectively.

TABLE I

The vegetative cycle and earliness in anthesis in the different plants worked upon

Plant	Date of sowing	Vegetative cycle in days		Earliness in days	Value of 't'
		C*	V*		
Brassica	31-10-49	55·5 (14)**	42·0 (13)	13·5	16·5
Eruca	12-10-49	61·7 (10)	32·7 (15)	29·0	47·9
Lens	20-10-49	94·7 (15)	67·5 (15)	27·2	26·4
Cicer	20-10-49	87·2 (9)	60·8 (12)	26·4	28·4
Lathyrus	20-10-49	110·9 (12)	97·5 (11)	13·4	8·4
Pisum	20-10-49	98·8 (15)	91·4 (20)	7·4	6·3
Linum	20-10-49	89·4 (14)	41·1 (15)	28·3	33·2

* C—control, V—vernalised

** Number of plants are given within brackets

Vascular differentiation

Radicle. The general anatomy of mustard radicle with special reference to vascular differentiation has been presented in a separate communication [Chakravarti, 1953a]. Embryos soaked for six hours have their traces in procambial stages only [Chakravarti, 1953a, fig. 1]. In the unsplit seeds of mustard vernalised for three weeks, one differentiated phloem element at each of the poles is seen in addition to the same number of xylem ones (Plate IX, fig. 1).

In the radicle of just splitting untreated seeds, one sieve tube at each of the protophloem poles, is found to be completely differentiated but the protoxylem elements are still at various stages of development. In certain roots, two protoxylem element one at each of the poles have completely lost their protoplasmic contents and their walls lignified, while in others, their protoplasm has started contracting and walls do not stain with safranin. In the corresponding vernalised seeds the number of mature sieve tube elements at one pole varies from one to two and that of xylem elements, two to three. A comparative study, therefore, clearly points out that the differentiation of both xylem and phloem elements in the radicles of seedlings raised from vernalised seeds takes place earlier.

Cotyledonary traces. It has been shown in a previous communication [Chakravarti, 1950] that there is an early vascular differentiation in the cotyledonary traces of the vernalised seeds. The same condition is maintained in the growing seedlings

11A

as would be seen from Table II. There is not only a progressive increase in the number of xylary elements with an advance in the age of the seedlings, but the rate of its formation is definitely more rapid in the treated than in the untreated ones. The stationary condition on the seventh day over what is seen on the sixth in both treated and untreated plants might be due to an equality between new additions through the activity of the cambium and obliteration of the primary ones.

Phloem counts in the cotyledonary traces could be made up to an age of two days only. In seedlings older than this, it is very difficult to differentiate between a sieve tube and a vacuolating parenchyma. Here the numbers of mature and immature sieve tubes at the level of the shoot apex are on an average 4·0 and 5·2 in the untreated and treated seedlings respectively.

TABLE II

Number of xylary elements per cotyledonary trace at the level where sections pass through the stem tip

Age of the seedlings in days	Number of xylary elements	
	Control	Vernalised
2	2·2	8·8
3	7·2	15·3
4	7·7	17·6
5	24·0	27·5
6	29·7	32·5
7	29·5	32·8
9	33·8	41·0

Cotyledons. The condition of the veins of the cotyledons in the just sprouting untreated seeds is represented in Plate IX, fig. 3. Here all of them are in the procambial stage while majority of these in the corresponding treated ones show well differentiated xylem (Plate IX, fig. 4) and phloem elements.

First leaf. In the first leaf of a two days old seedling, all the traces are in the procambial stage. In the corresponding treated ones, out of the four materials examined, two are in the same stage as that of the control, while in the other two, there is one mature sieve tube in each median trace over a considerable length. This indicates that as in the cotyledonary traces so also in the traces of the first leaf, there is an early differentiation of the phloem elements in the seedlings raised from the treated seeds.

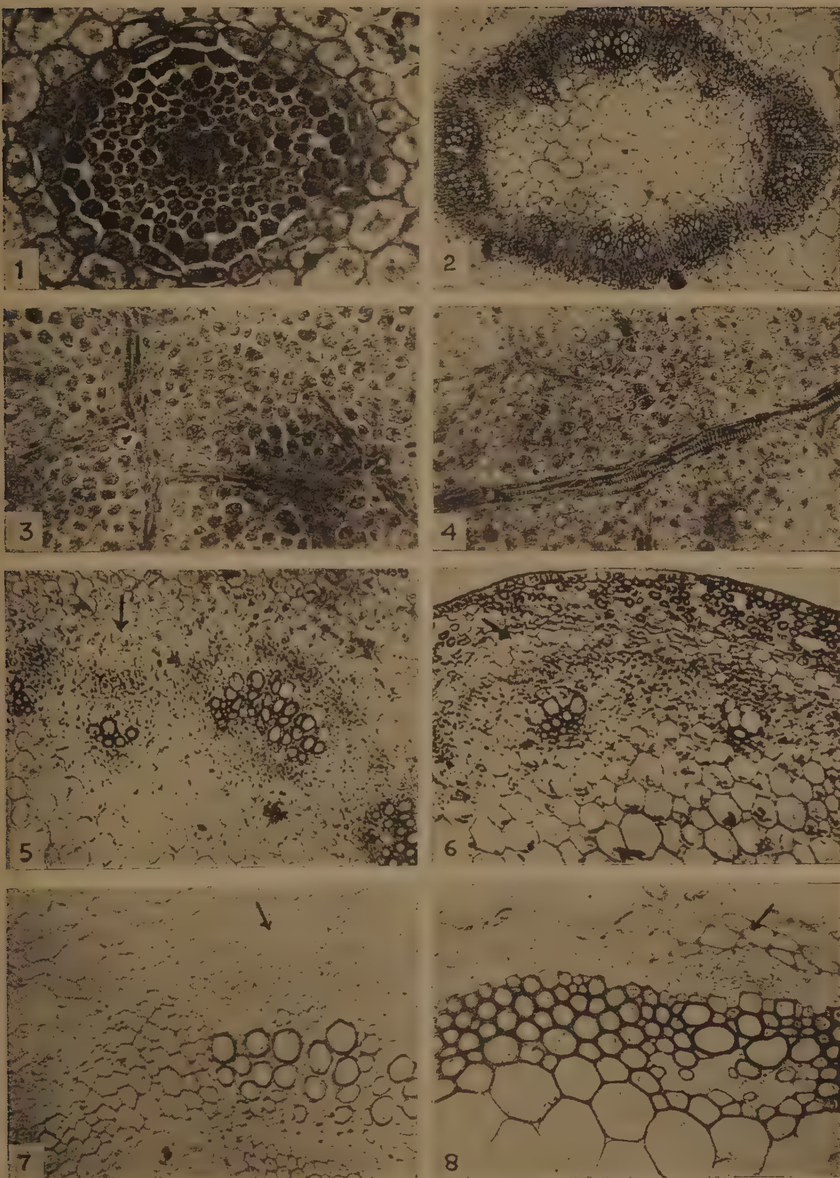


FIG. 1. Transverse section of the radicle of an unsplit seed of mustard vernalised for three weeks showing two phloem (upper and lower) and two xylem (right and left) elements differentiated. x 195.

FIG. 2. Transverse section of fifteen days old vernalised stem of mustard above the attachment of the cotyledons. x 38.

FIGS. 3, 4. Sections parallel to the surface of the cotyledons of just splitting normal and vernalised seeds. x 378.

FIGS. 5, 6. Transverse sections of stems of 37 days old normal and vernalised plants of mustard. Arrow indicates bundle cap cells. Fig. 5 x 52. Fig. 6 x 111.

FIGS. 7, 8. Transverse sections of stems of 45 days old control and vernalised plants of mustard. Arrow indicates bundle cap cells. x 378.

Adult shoot apices. A comparative study of xylem counts in the median traces of the different leaves in the shoot apices of fifteen days old plants raised from treated and untreated seeds (Table III), indicates that the leaves to have first differentiated xylem elements are younger on the former than on the latter. In all the five plants obtained from treated seeds, the mediant race of the fourth leaf counted from the apex has either a mature, or an immature, or both the types of xylem elements; while in the corresponding controls two plants out of seven show this feature. The above-mentioned facts are of great interest and there is hardly any other observation along similar lines with the exception of those of Esau [1945]. She, working with several plants, came to the conclusion that greater the crowding of the leaves on the apex the slower is the vascular differentiation in them. However, this cannot explain the observed facts in mustard as the number of leaves on both the treated and untreated plants at the age of 15 days is eight.

TABLE III

The maximum number of xylary elements in the median traces of the fourth leaf of 15 days old shoots of mustard

(*First three leaves have their traces in procambial condition*)

Number of plant	Control		Vernalised	
	Mature	Immature	Mature	Immature
I	0	0	0	1
II	0	0	0	1
III	0	0	1	0
IV	0	0	1	1
V	0	0	1	1
VI	0	1	..	..
VII	0	2	..	..

Apical meristem

Organisation of the apical meristem of mustard from the resting embryo to the onset of the reproductive phase has already been described [Chakravarti, 1953b]. The first noticeable difference between the seedlings raised from treated and untreated seeds lies in the activity of the rib meristem which starts in the former a day earlier that is at the age of five days. The phase of elongation of the cells

produced by the division of the rib meristem is again completed earlier in the treated seedlings as would be seen from the fact that in nine days old control seedlings, the uppermost cells of the pith which are in immediate contact with the rib meristem are still elongated in the direction parallel to the long axis of the plant (Fig. 1) while those in the corresponding vernalised ones are elongated in the transverse direction (Fig. 2). Activity of the rib meristem has already started in the latter.

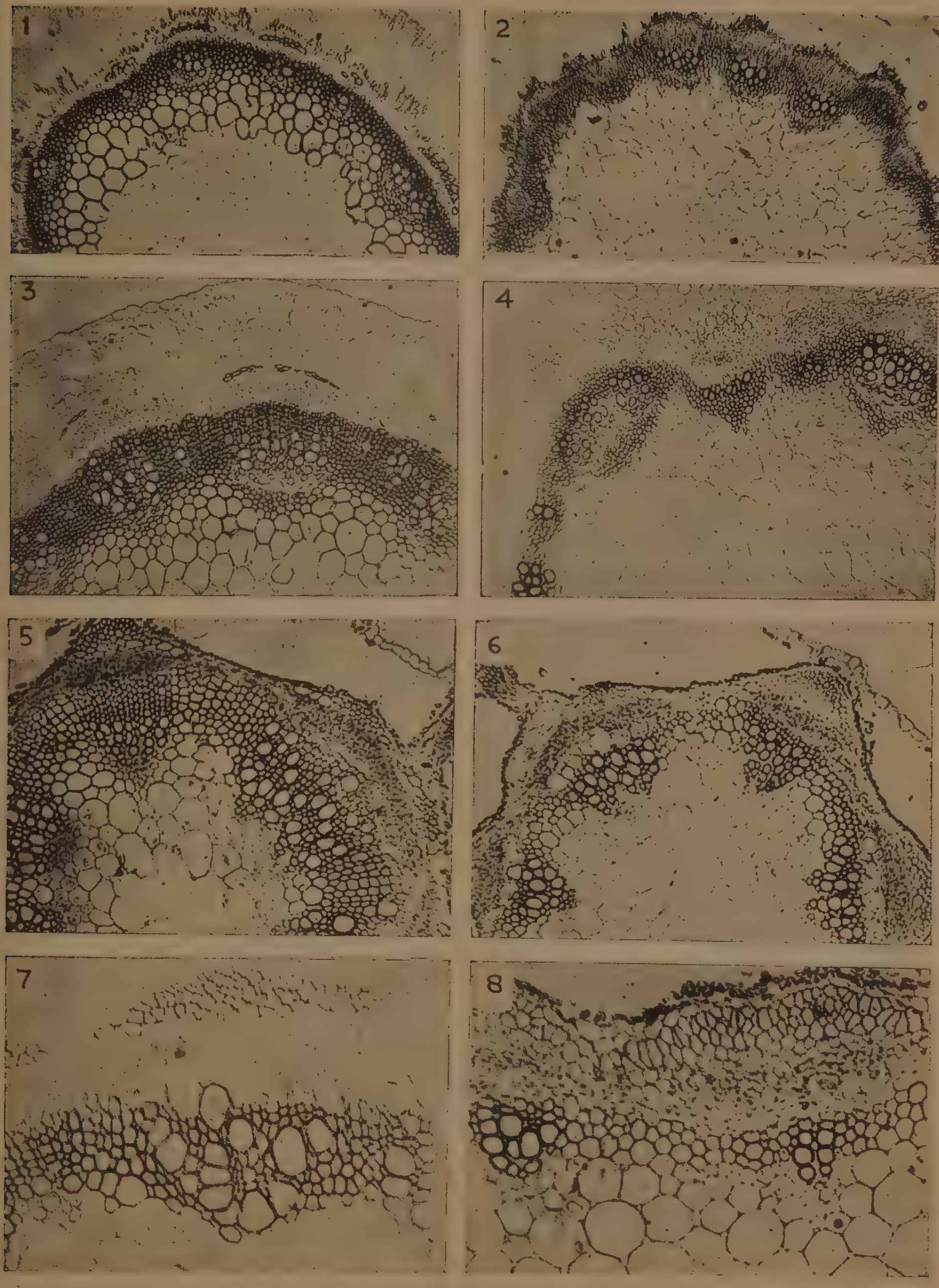
In fifteen days old treated and untreated plants no difference in the activity of the rib meristem can be recorded but the number of tunica layers are definitely more in the former. In control plants out of the apices of seven (median or semi-median sections), two have three tunica layers while the rest have two. In the corresponding vernalised plants, out of the eight shoots examined, there are two apices with two tunica and the rest with three tunica layers. Thus, the three layered condition, which is more advanced [Chakravarti, 1953b], is reached earlier in the treated plants. At an age of 22 days, the apices of the treated plants have all the characteristics of a reproductive shoot in that they possess three to four layers of tunica composed of more or less columnar cells with one or two layers of underlying cells stratified [Chakravarti, 1953b, fig. 4]. In contrast to this the apices of the untreated plants possess a three-layered tunica, the cells of which are in transition from the tangentially elongated to the radially elongated condition.

Fig. 1. Fig. 2.

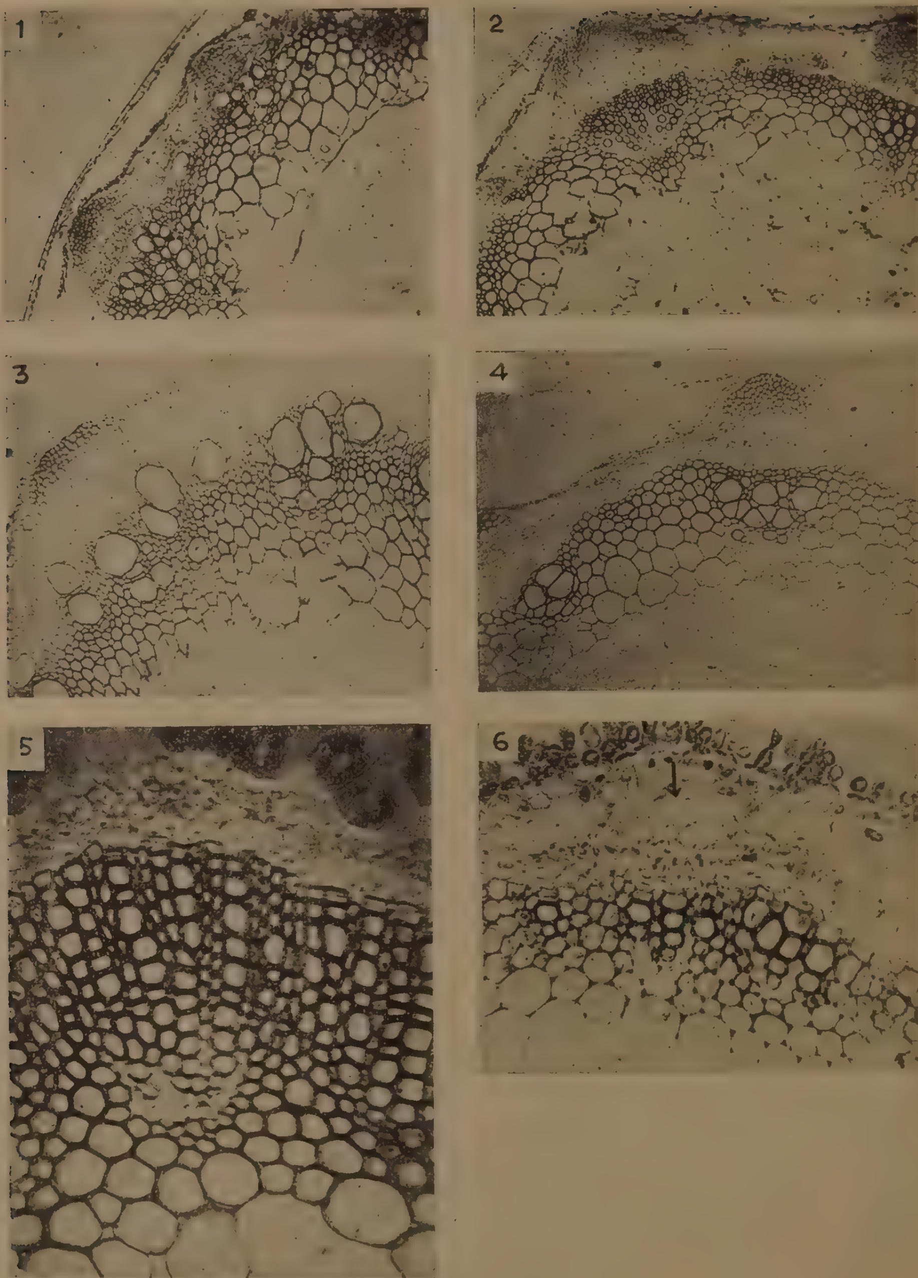
Figs. 1 and 2. Longitudinal sections of portions of shoot tips showing the condition of pith in nine days old control and vernalised seedlings respectively. ×190.

Mature stem structure

Brassica campestris L. A comparative study was undertaken from samples collected at the ages of 15, 37, 45, 56 and 70 days. In 15 days old control and vernalised plants serial transverse sections from the shoot tip to the cotyledonary node



FIGS. 1, 2. Transverse sections of stems of 56 days old vernalised and control plants of mustard. x 44.
FIGS. 3, 4. Transverse sections of stems of 70 days old vernalised and control plants of *Eruca.* x 45.
FIGS. 5, 6. Transverse sections of stems of 82 days old vernalised and control plants of *Lens.* x 138.
FIGS. 7, 8. Transverse sections of stems of 82 days old vernalised and control plants of *Cicer*, x 106.



FIGS. 1, 2. Transverse sections of stems of 104 days old vernalised and control plants of *Pisum*. x 31.

FIGS. 3, 4. Transverse sections of stems of 113 days old vernalised and control plants of *Lathyrus*. x 75.

FIGS. 5, 6. Transverse sections of stems of 67 days old vernalised and control plants of *Linum*. Arrow in figure 6 indicates thin walled cells just opposite the phloem region which at a later stage of development give rise to fibres. Fig. 5 x 210; Fig. 6 x 222.

had to be studied as there was no elongated internode suitable for sampling. There is practically no difference in the anatomical condition of these two types of plants and a vigorous cambial activity is recorded in both (Plate IX, fig. 2).

In the second slightly elongated internode of 37 days old control plants (Plate IX, fig. 5), cells below the primary xylem point, of the medullary rays and of the phloem are rich in protoplasmic contents. The latest formed xylem elements are large vessels with practically no lignification and the pericyclic zone (bundle cap) is equally thin-walled and thus can not be demarcated from the surrounding cortical cells easily. In a vernalised plant of the same age (Plate IX, fig. 6), the number of layers of cortical cells is less, the pericyclic zone clearer and the walls of the medullary ray cells thicker. The latest formed xylem elements are comparatively smaller vessels mixed with thin-walled parenchyma.

At the age of 45 days, when the vernalised plants are in flowers, the difference between the stems of untreated and treated plants (Plate IX, figs. 7, 8) as regards the thickening of the walls of the bundle cap cells, medullary ray tissue and perimedullary zone is highly marked. Most of the cells of the latter two regions and xylem are optically empty in the vernalised plants only. In contrast to the control plants, they do not have many large vessels as the latest formed xylem elements.

In control plants 56 days old (Plate X, fig. 2), the second elongated internode shows remarkable changes in its tissues. Thickening of the medullary ray cells and of the parenchyma below the primary xylem point is quite evident. There is a decrease in the protoplasmic contents of the cells of the interfascicular region. Pericyclic cells against the primary phloem are now very well distinguished and they possess slightly thick walls. The cells of the medullary rays, perimedullary zone and pericycle do not retain any crystal violet stain.

In vernalised plants of the same age (Plate X, fig. 1), the cells of the interfascicular region have become still more thick-walled and majority of them along with the bundle cap cells now retain the basic dye. The walls of the phloem cells are also slightly thickened and more compressed than their prototypes in the untreated plants. There is hardly any vessel among the latest formed xylem and a number of thick-walled smaller elements have made their appearance in contrast to none in the corresponding control. Distinct signs of disintegration of the thin-walled parenchyma of the medulla is noticeable in the treated plants while this tissue in the corresponding control ones is more or less intact.

After a lapse of another two weeks, the stems of both treated and untreated plants have become woody. The main difference between them now lies in the staining reaction. In the former, the entire xylem, medullary rays, perimedullary zone and bundle cap cells are deeply stained with crystal violet while in the latter all these zones with the exception of earliest formed xylem elements are comparatively lightly stained with the same dye.

Rest of the plant materials have practically the same story to repeat. When young, both vernalised and control stems possess equally active cambium. The data are presented in Table IV and in Plates X and XI.

TABLE IV

The anatomical differences that exist between the vernalised and control plants at certain selected ages when the contrast between the two treatments is most marked

Plant	Age in days	Figures	Tissues	Differences
Eruca	70	Plate X Fig. 3, 4	Bundle cap	Cells in C plants are slightly thick-walled and stain with erythrosin while in V plants they are highly thick-walled and take crystal violet stain.
			Cambium	Completely differentiated in V plants while in C plants it is not so.
			Xylem	Latest formed elements in C plants are differentiating vessels, while in V plants they are small, oblong and thick-walled.
			Phloem	In C plants the cell wall of this tissue is thin while in V plants it is quite thick and the tissue highly compressed.
			Perimedullary zone	In C plants this region is composed of thin-walled cells stained with erythrosin. In V plants the cells are highly thick-walled and deeply stained with crystal violet.
			Medullary rays	Condition more or less similar to that of the cells of the perimedullary zone.
			Medulla	Partly disintegrated in V plants.
Lens	82	Plate X Fig. 5, 6	Xylem	Latest formed vessels in C plants have wider lumen. In V plants thick-walled smaller elements have also appeared.
			Phloem	Thickening of the cell wall of this tissue can be noticed in V plants only.
			Perimedullary zone	Cell walls in V plants thicker.
			Medullary rays	Rows of thick-walled cells in V plants are more and they take deeper crystal violet stain.
Cicer	82	Plate X Fig. 7, 8	Cambium	Both fascicular and interfascicular cambium in C plants are quite active and several layered while in V plants this tissue is completely differentiated.
			Xylem	Latest formed elements are almost all large vessels in C plants. In V plants a number of smaller elements have also made their appearance.

TABLE IV—(*contd.*)

The anatomical differences that exist between the vernalised and control plants at certain selected ages when the contrast between the two treatments is most marked

Plant	Age in days	Figures	Tissues	Differences
			Phloem	Walls of cells slightly thicker in V plants.
			Medullary rays	Cell walls in V plants are much thicker and they take light crystal violet stain in contrast to erythrosin taken by those in C plants.
Pisum	104	Plate XI Fig. 1, 2	Perimedullary zone and medullary rays	These zones in V plants are composed of thicker and deeper crystal violet stained cell walls.
Lathyrus	113	Plate XI Fig. 3, 4	Bundle cap	Cell walls thicker and a larger number of cells are stained with crystal violet in V plants.
			Xylem	There are more differentiated vessels in V plants and they all have thicker walls.
			Medullary rays	More cells are crystal violet stained in V plants.
Linum	67	Plate XI Fig. 5, 6	Bundle cap	In C plants the cells of this region which later on give rise to fibres are extremely thin-walled and full of protoplasm. In V plants these cells have completely changed into thick-walled fibres.
			Cambium	Cambium in both can no more be differentiated but the nature of latest-formed xylem elements indicate that it was active quite late in C plants.
			Xylem	Latest-formed elements in C plants are large non-lignified vessels in the process of differentiation. In V plants the entire xylem is woody and the latest-formed elements are distinctly small and radially arranged.
			Phloem	Cells in V plants are thicker-walled and the entire tissue compressed.
			Perimedullary zone	The entire zone in V plants stains deeply with crystal violet while in C plants it takes erythrosin.
			Medullary rays	In V plants the cells of this region are thicker-walled and take deep crystal violet stain in contrast to erythrosin in C plants.
			Medulla	Non-lignified cells in V plants are disintegrated while all cells in C plants are intact.

A comparative study of the mature stem structure presented in the foregoing pages reveals that for the same age, vernalised plants possess a more mature anatomical condition as depicted by the increased thickening of the walls of the bundle cap cells, pericyclic fibres, medullary rays, perimedullary zone and phloem and also by a greater affinity of most of them for the basic dye crystal violet and an early cessation of the cambial activity as revealed by the nature of the latest-formed xylem elements. The contrast becomes highly conspicuous when the vernalised plants approach maturity.

Discussion

Increased vascular differentiation in the seedlings of mustard as a result of low temperature treatment is remarkable. Bassaraskaja [1934], however, failed to find any structural difference in cereals and Whyte [1946] also holds the same view.

Thimann [1948] has made the suggestion that early flowering in a vernalised plant may result from the differences in the supply system and therefore, the materials made available to the developing initials. In the present study, however, ample evidences have been collected in support of the same. It is true that there is hardly any significance of this earlier vascular differentiation in an embryo where the problem of transport is practically nil, but it is definite that the vernalised seedlings during the process of their subsequent growth get an advantage over the normal ones in having an elaborated transporting system. In the adult plants too, the vernalised ones in having differentiated xylem elements in their fourth leaf from the apex are in a better position of transport than the control ones where these elements mostly occur in the next lower leaf.

Wilton and Roberts [1936] and Wilton [1938] as well as Roberts and Struckmeyer [1948] have shown that there is a direct relationship between the flowering impulse and the activity of the cambium. Struckmeyer [1941] has demonstrated it for photoperiodically treated plants in which he finds a decrease in the cambial activity in plants placed in a day-length favourable for flowering. He further observes that the activity of the cambium increases again when some of the treated plants are returned to the original light conditions before the photoperiodic induction is complete. It has not been possible in the present studies, however, to detect such an abrupt change and all the vernalised plants have a normally developed cambium. This clearly indicates that the substance or substances formed during chilling are not direct flower forming ones and are thus quite different from what are produced during the photoperiodic treatment. Induction of further earliness in anthesis in plants raised from 'maximally' vernalised mustard seeds subjected to long days [Sen and Chakravarti, 1942] also supports the same view. Similar conclusions have been arrived at by several workers [Lang, 1952; Melchers, 1952] working with cereals and two separate names 'vernalin' and 'florigen' have been suggested for them.

It is interesting to observe that the substance or substances formed during prechilling treatment not only bring about early flowering but also have their influence on tissue differentiation and growth. Chand [1950] working on several strains of vernalised and control mustard, has shown that the treated seeds germinate more quickly and the seedlings have a greater accumulation of dry weight during the earlier part of their life-cycle in comparison to the normal ones. Later on, the former are, however, superceded by the latter. The same author has also recorded an early appearance of primary and secondary branches on the treated plants which are definitely growth characters and are by no means associated with reproduction.

Working with *Kalanchoë*, Harder [1948] has observed that short photoperiodic treatment in this plant not only induces early flowering but brings about certain morphogenetic effects. In his opinion, the latter is due to the formation of a separate substance, 'metaplasin'. Further work is, however, needed to show if in vernalised mustard seeds as well, two different groups of active principle exist, one controlling flower production and the other tissue differentiation and growth.

Summary and conclusions

1. The present investigation has been undertaken to make a comparative study of the anatomy of normal and vernalised seeds of mustard, seedlings and plants raised from them and of the mature stem structures of six other dicotyledonous plants known to respond to vernalisation treatment.

2. Due to treatment the following processes are found to be earlier : (i) Vasculer differentiation in the radicle, cotyledons and their traces, (ii) the appearance of an increased number of tunica and the changes in the shape of its cells and (iii) the activity of the rib meristem.

3. For the same age, vernalised plants possess a more mature anatomical condition. They have an increased thickening of the walls of the bundle cap cells, pericyclic fibres, medullary rays, perimedullary zone and phloem and also a proportionately greater area taking the basic dye crystal violet in comparison to erythrosin and an early cessation of the activity of the cambium. These differenecs between the anatomical condition of the vernalised and control plants become more and more pronounced as the former approach maturity.

In view of the presence of a normally active cambium in vernalised plants, it is concluded that the substance or substances formed during low temperature treatment is not a direct flower forming one and thus differ from what are synthesised during the photoperiodic treatment where signs of decreasing activity of the cambium is recorded even before the flower buds are visible.

Acknowledgement

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REVIEWS

STATISTICAL YEARBOOK 1952

(*Prepared by the Statistical Office of the United Nations, Department of Economic Affairs, New York, Price, Cloth bound—$7·50, Paper bound—$6·00*)

THE present volume, which is the fourth issue of the United Nations Statistical Yearbook, is a carefully prepared and comprehensive compendium of statistics covering a very wide range of activites of almost all the countries in the world. There are 177 tables of data suitably annotated. The statistics relate to such diverse topics as population, agriculture, industry, transport and communications, trade, finance and social welfare. Index numbers of agricultural and industrial production, of whole-sale prices, cost of living, etc., are also included. These should be of immense reference value to students, administrators, businessmen, industrialists and others. The study of the index numbers given would be facilitated if the notes on their construction are provided in the volume itself instead of referring the reader to some other source for a description. Most of the data cover a period from 1932 or from 1936 to 1952 and every attempt is made to give them in the form of comparable series. In considering the geographical coverage of the data, the reader is struck by the omission of information relating to China and U.S.S.R. This is a serious gap, which, however, in the present circumstances appears unavoidable.

Statistical publications, like the present one, are some of the visible benefits resulting from the setting up of United Nations and other International Organizations. In the preparation of the present volume, a number of these International Bodies have co-operated with the U. N. Statistical Office. This office is to be congratulated for bringing together a wealth of quantitative information contained in the present volume. (V. G. P.)

LAND RESOURCES

PROCEEDING OF THE UNITED NATIONS SCIENTIFIC CONFERENCE ON THE CONSERVATION AND UTILISATION OF LAND RESOURCES, Vol. VI.

(*United Nations Publications, 1951, Price $6*)

THIS volume contains 147 papers contributed by specialists from different countries of the world on problems of conservation and utilisation of land resources. The volume is divided into 14 chapters, of which four chapters deal with soils, their fertility, conservation, survey, research and organisations of the programmes relating to these topics. These are four chapters dealing with grazing lands, their condition, protection, utilization and more effective use by seeding and restoration. There also are papers dealing with the problem of protecting cattle from pests and diseases, and their improvement by breeding, protecting stored products from destruction, plant breeding, crop policy and feeding of livestock. One chapter is devoted to farm implements and mechanisation of agriculture. Majority of contributors in their papers have dealt with the extent of the gravity of the problems in their countries, steps taken towards the solution of these and the difficulties encountered. Some papers deal with problems in the world as a whole and contain useful recommendations.

The contributors of papers on soil conservation have drawn attention towards the need for using all known methods of soil conservation in combination, so as to obtain best results from the land according to its capabilities. Terracing, contour, tillage, strip cropping, rotation grazing, gully sloping, planting shelter belts and wind breaks have been recognised as suitable methods for erosion control, while such measures as drainage, irrigation, manuring and crop rotation can successfully make up temporary loss of fertility and these must be combined to obtain the maximum out of the land resources. The defective land tenure system resulting in fragmentation of holdings is the principal difficulty in many countries and proper legislative measures for successful soil conservation programme is essentially based on a broad national programme. It has been suggested to create a national conservation organization which should take up soil and water conservation research and set up local stations for technical assistance. Practical demonstration of soil conservation methods, necessary advice and financial help are to be given to encourage the adoption of proper system of farming. Soil survey to determine the characteristic of soil and to predict their adaptibility to suitable crops have been considered as a prerequisite for any soil conservation programme. The tropical belt offers great potential areas of new agricultural land where luxurious plant growth is possible, and about five million square miles of new land can be reclaimed for this purpose with proper planning. The problems of increasing productivity of soils by manuring, irrigation and suitable cropping systems have been discussed from various angles.

In the chapter on ' Aids to Farming ' several papers on mechanisation of farming have been presented. It has been pointed out that simple tools and equipments for small scale farming, specially designed for cheapness and simplicity are badly needed.

Regarding the utilisation of land resources by cropping, several plants can now be successfully grown in arid regions where nothing could be grown before. Importance of plant breeding which has enormously increased crop production, at a very small expense in relations to the benefits derived has been pointed out. Survey, collection and conservation of world's gene resources are essential for a world wide breeding programme. Breeding of crops which were neglected so long and of the forest trees are likely to give similar profitable results. The plants grown are to be protected from various diseases, which form the greatest obstacle for efficient and stable agricultural production. Relative merits of the methods available for controlling diseases have been discussed and it has been suggested to create an organisation for dissemination of information on the control measures. Then there is a problem of wastage after harvest. For storing agricultural products, temperature and moisture control and proper sanitary conditions are essential ; the great advance which has been made in storage equipments and food preservation, has been discussed.

Non-arable lands have been neglected and allowed to deteriorate practically throughout the world. The maximum return from these grasslands depends not only on an efficient farming system, but also on the animals which are capable of utilising grasses with maximum efficiency. Several papers have described the

progress of livestock breeding and the part played by certain physiological characteristic. There is a great scope for artificial insemination. Besides breeding, great improvements might be made by efficient feeding methods and by taking measures towards prevention of livestock diseases. (S. V. A. and J. C. G.)

METHODS AND PROBLEMS OF FLOOD CONTROL IN ASIA AND THE FAR EAST

(Prepared by the Bureau of Flood Control of the Economic Commission for Asia and the Far East)

THIS is the second issue of the ' Flood Control Series ' prepared by the Bureau of Flood Control of the Economic Commission for Asia and the Far East for pooling the experience and knowledge in flood control both within and outside the region. Material for this study has been obtained by the experts of the Bureau during their field trips to various countries of the region and from technical literature on this subject.

In the introduction, a brief study of the nature of the problem has been made. Chapter I reviews the flood control methods employed on various rivers of the region, including the Irrawaddy in Burma, the Gin Ganga and Nilwala Ganga in Ceylon, the Huai, Pearl, Yangtze and Yellow in China, the Brahmaputra, Damodar, Mahanadi, Ganges, Kosi, Godavary, Krishna and Cauvery in India, the Red and Mekong in Indochina, the Solo and Brantas in Indonesia, the Indus in Pakistan, the Pampanga and Agno in the Philippines, the Chao Phya in Thailand and the Tone and Kiso in Japan. The various flood control works which were developed and used from the earliest uncoordinated and scattered dikes and haphazard river training to the recent multipurpose reservoirs and other works planned according to the modern concept of unified river basin development are fully discussed. The basic features of the dikes constructed on various rivers and the techniques for their protection and maintenance from flood damages are given along with necessary drawings and figures.

Chapter II deals in general with the problems of flood control. The essential controlling river characteristics based on which the classification of the rivers of the region into stable and unstable rivers are made, the engineering effectiveness and the cost of construction and upkeep of dikes, the usefulness of river training methods, and the role of storage, detention and diversion works in flood control are studied. The problems of soil and water conservation as related to flood control are also dealt briefly. A note on the design flood and food forecasting for successful reservoir operation and on the economics of flood control is also included.

The conclusion recommends critical examination of all possible flood control works and a judicious selection of the one which will yield the highest benefit-cost ratio. It is pointed out that the methods of flood control at present employed in the A.F.E. region, where flood is a constant menace, show a close relationship with the progress of economic development and that any improvement in the methods of flood control is of major significance to the improvement of living standard in that region. (S. K. G.)

FARM GAS ENGINES AND TRACTORS

By FRED R. JONES

(Published by Mc-Graw Hill Book Co. Inc., New York, 1952)

THIS book which is one of the publications under the Agricultural Engineering Series, is written by Professor F. R. Jones, of the Texas A. and M. College. The first edition was brought out in 1932. The third edition includes some of the latest developments such as L. P. Gas as Tractor Fuel. This is a very common text-book in all the Agricultural and Mechanical Colleges of the U. S. A. (known as A. and M. Colleges), in the field of Agricultural Tractor Power, for students of general agriculture, agricultural engineering and agriculture extension. The book is also used in the U. S. A., by students taking mechanical and electrical engineering, for the subject of I. C. Engines or Heat Engines.

As we are hitherto used to British text-books in India until very recently it does not seem to have become known, to the extent it deserves in India. Also, there is one other factor, which is holding up the popular use of this book and that is due to its title 'Farm Gas Engines and Tractors'. The Americans call petrol as gas which is a shortened form of gasolene and hence this book is really on Internal Combustion Engines and Tractors, which is a right title for Indian conditions.

The contents of this book are dealt with from elementary principles, and hence can be easily understood even by those who have no fundamental knowledge of physics or mathematics. Mathematical calculations are kept to a minimum and the book can be used as a guide, by farmers, who are interested in the purchase and maintenance of the tractor. The book will be of use in our engineering colleges or schools for teaching about I. C. engines and automobiles. For the commercial group, which handles the purchase and sale of tractors, informatoin on testing of tractors, rating and testing procedures for the same is useful. As mechanisation is making some progress in India, this book should also be of interest to agricultural officers, students in agriculture and the farming class in general.

The book, which is primarily meant as a text for U. S. Land Grant Colleges deals mostly with American tractors and their standards. Countries outside the Western hemisphere are using tractors from continental countries also and in particular from the U. K. and Germany. Some of the latest developments in tractor design, such as diesel tractors and air-cooling of engines have not been given due prominence. While there is a separate chapter on diesel engines, more than what is given here would be necessary for students and users of tractors in India. While there is a trend towards an increase in the production of diesel tractors particularly for the foreign markets, the U. S. A. uses a comparatively very small percentage of agricultural tractors on diesel fuel. This aspect will not diminish the value of the book to college students and users of petrol or kerosene tractors.

There are British text-books on the subject of agricultural machinery and tarctors but the subject is not covered as extensively in the British text-books. As mentioned earlier, the book may find an increasing use in our Engineering and Agricultural Colleges, as well as amongst the trade and interested farmers. The language is simple and free from highly technical terms and the material is easily understood. (R. V. R.)

BOOKS RECEIVED

1. Proceedings of the Society for the Study of Fertility
2. Special Independence Day Number of the Bulletin issued by the Indian Central Coconut Committee

MGIPC—M—6 AR/53—29-1-54—880.

The Editorial Board in its work of examining papers received for publication, is assisted in an honorary capacity by a large number of scientists working in various parts of India.

Editorial communications including books and periodicals for review should be addressed to the Secretary, Indian Council of Agricultural Research, Publication Section, New Delhi.

Communications regarding subscription and advertisements should be addressed to the Manager of Publications, Civil Lines, Delhi.

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Articles intended for *The Indian Journal of Agricultural Science* should be accompanied by short popular abstracts of about 330 words each.

In the case of botanical and zoological names the International Rules of Botanical Nomenclature and the International Rules of Zoological Nomenclature should be followed.

Reference to literature, arranged alphabetically according to authors' names, should be placed at the end of the article, the various references to each author being arranged chronologically. Each reference should contain the name of the author (with initials), the year of publication, title of the article, the abbreviated title of the publication, volume and page. In the text the reference should be indicated by the author's name, followed by the year of publication enclosed in brackets; when the author's name occurs in the text, the year of publication only need be given in brackets. If the reference is made to several articles published by one author in a single year these should be numbered in sequence and the number quoted after year both in the text and the collected references.

If a paper has not been seen in original it is safe to 'state original not seen'. Sources of information should be specifically acknowledged.

As the *format* of the journal has been standardized, the size adopted being crown quarto (about 7½ in. 9¾ in. cut) no text figure, when printed should exceed 4½in. × 5 in. Figures for plates should be so planned as to fill a crown quarto page, the maximum space available for figures being 5¼ in. × 8 in. exclusive of that for letter press printing.

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